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REGULATORY AND TECHNOLOGICAL CHANGE IN THE TRUCKING INDUSTRY: AN ASSESSMENT OF IMPACTS ON OPERATING COSTS

PROJECT REPORT NO. 3

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REGULATORY AND TECHNOLOGICAL CHANGE IN THE TRUCKING INDUSTRY:

An Assessment of Impacts on Operating Costs

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REGULATORY AND TECHNOLOGICAL CHANGE IN THE TRUCKING INDUSTRY
An Assessment of Impacts on Operating Costs

by

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Chapter 1

BACKGROUND

1.1 Introduction

The purpose of this study is to examine regulatory and technological changes in the trucking industry that are likely to occur over the next ten years and to assess their impact on trucking costs. These changes are examined through an exhaustive review of the literature (both scientific and trade sources), as well as through interviews with government officials, truck engine manufacturers, and for-hire trucking firms. Based on past trends and current pressures, likely changes in the existing regulatory system are identified. As well, recent developments and current research in technology are surveyed to evaluate future improvements and their potential application. After key regulatory and technological developments are discussed, their impacts on linehaul trucking costs are assessed.

The scope of the study is quite general in order to address a wide range of regulatory and technological issues. But although key developments can be identified in general terms, their cost impacts cannot be quantified unless certain operational details are specified. Operating costs vary for different vehicle combinations and routes since conditions (eg., wage rates, vehicle utilization, licence fees) vary considerably across the country. In order to provide consistent comparisons, therefore, two basic types of vehicles are selected (a tandem-tractor with a 45-ft. semi-trailer, and a tandem-tractor with two 27-ft. semi-trailers) and cost analysis is confined to four specific routes (Toronto-Halifax, Toronto-Montreal, Toronto-Winnipeg, and Toronto-Vancouver).

The assumptions and the procedures used in estimating trucking costs, which are documented in detail in Appendix A, are based on CN Rail's costing method (CN Rail 1983). In the regulatory area, changes in unit costs are due primarily to increased productivity and lower labour costs, which can be quantified using readily available cost information. The cost impacts of technological improvements, however, are primarily due to reduction in fuel consumption. In order to estimate these impacts, more detailed simulation of energy consumption was necessary to complement the cost analysis. The vehicle simulation model used for this purpose is documented in Appendix B.

Despite every effort to obtain the most accurate and objective data, judgemental assumptions had to be made in many instances and the experience of the study team had to be relied upon. Given the uncertainty about the future and the highly politicized nature of the regulatory system, some of the views expressed in this report remain subjective and speculative.

1.2 Regulation

Although all aspects of commerce are affected in one way or another by government regulation, in the case of trucking, economic regulation is more direct. In all provinces, entry into for-hire trucking is controlled by a licensing mechanism, whereby regulatory agencies retain the power to grant, cancel and control the transfer of licences. In general, licences are granted or refused on the basis of "public interest, need, or convenience." Moreover, provincial authorities have a wide range of powers to control the nature, type, and/or quality of services provided by licensed carriers. Some provinces also have the authority to set rates, or at least to require that rates be filed and approved.

The existing regulatory systems governing the for-hire trucking industry are under review in almost every province in Canada. Although it is difficult to assess the attitude towards economic regulations, and thus difficult to forecast the outcome of the current review process, a number of influential factors can be identified. The experience with deregulation in most spheres of transportation activity in the United States is of immediate relevance. Although Canadian authorities have been less enthusiastic about deregulation, some fundamental questions continue to be raised about the need for direct economic control in the transport sector.

Recent studies by the Economic Council of Canada, Transport Canada, the CTC, and Consumer and Corporate Affairs have fallen short of demonstrating the effects of regulation, but have fuelled the policy debate in favour of deregulation. While dealing primarily with the reform and clarification of interprovincial differences in regulation, the activities of the Canadian Conference of Motor Transport Administrators (CCMTA) have also raised some fundamental questions about the role of economic regulation in the trucking industry.

Chapter 2 deals with these issues in more detail and examines the regulatory review activities across the country, assessing the likelihood of major changes in the economic regulation of for-hire trucking over the next ten years.

While this study focuses primarily on for-hire trucking, there are a number of important developments underway in other segments of the industry that might have impacts on the rates and costs of for-hire trucking. Regulatory changes that may affect the role and scope of private trucking, for example, would naturally have indirect impacts on the for-hire industry. If entry restrictions were relaxed, it is conceivable that private fleets could be used for for-hire carriage. In the current regulatory debate, those in favour of deregulation often argue that the empty backhauls in private trucking lead to inefficient resource utilization which could be corrected by permitting private fleets to engage in for-hire carriage. This would allow private companies to lower for-hire rates and generate transportation revenue on their empty backhauls to offset the costs of transporting their own goods.

Another important issue is the future of owner-operators in the for-hire industry. The use of owner-operators by established for-hire carriers has increased in the past few years. Owner-operators offer the industry an alternative source of capital, as well as lower labour costs. While enjoying these advantages, however, the industry is becoming increasingly concerned about the possibility of owner-operators working as independent truckers. It has become common practice, for example, to use owner-operators to haul exempt commodities (i.e., without an operating authority). If entry requirements were to be relaxed in other segments of the for-hire trucking industry, owner-operators could move into these markets as well. This has indeed been the trend in the U.S. since the passing of the Motor Carrier Act in 1980.

Chapter 3 discusses regulatory issues that affect the scope of private trucking, the changing role of owner-operators, and the possible emergence of independent trucking. Under certain conditions, these developments may indeed have significant impacts on the operating cost structure of the trucking industry.

The last set of regulatory issues addressed in this study concerns vehicle weights and dimensions. The maximum permissible size and weight of vehicles in Canada are governed by a complex set of rules concerning the width, height and length of vehicles; axle-weights; tire size and pressure; gross combination weights; and in some instances, minimum permissible power-to-weight ratios for large vehicles. Although efforts have been made in the past decade to standardize weight and dimension regulations across the country, considerable variations still exist. While there are no significant differences in single-axle weight limits across the country, there are major differences in tandem- and triple-axle load limits. The most restrictive limits on tandem-tractor/semi-trailer combinations are found in the Prairie provinces, where no additional weight is permitted with the use of a third axle on a semi-trailer. For double combinations, the most restrictive limits are in the Atlantic provinces. In all cases, Ontario and Quebec weight limits are the most liberal.

In general, the physical attributes of roads do not impose absolute limits on vehicle weight and dimensions. The apparent reasons for imposing weight and dimension limits are largely economic (e.g., maintenance costs increase with higher axle-loadings), and in some instances, simply arbitrary. Thus, they come under continual attack from the industry which has a vested interest in further relaxation of both weight and dimension limits in order to increase payload capacity and, therefore, productivity. In this context, lack of uniformity is often used to justify the relaxation of existing limits. The industry's lobbying efforts tend to be very effective since weight and dimension rules are not "cast in stone" based on any physical limits or criteria.

The trucking industry is currently lobbying for the relaxation and standardization of gross combination limits across the country, as well as for overlength vehicles such as triples, Rocky Mountain doubles, and turnpike doubles. The existing limits and continuing pressures for change are examined in detail in Chapter 4, where alternative scenarios are formulated and their impacts on unit operating costs (cents per unit payload - weight or volume - per unit distance) are assessed.

1.3 Technology

Although diesel engine technology is examined in more detail in Chapter 5, it is useful at this stage to provide some background on the introduction of the diesel engine and the gradual improvements that have been made in the last two decades.

The diesel engine has steadily replaced the gasoline engine in long-haul, heavy-duty tractors due to its superior fuel economy and greater durability. With rapidly rising fuel prices, the higher initial cost of the diesel engine could easily be justified for long-haul commercial operations. In the last few years, the gasoline engines have virtually disappeared from the long-haul trucking industry.

The automotive diesel engine was first turbocharged in the mid 1950s. Turbocharging increases engine efficiency by extracting work from the exhaust gas and by using the energy to operate a compressor to pack more air into the cylinders. The early to mid sixties saw the development of charge air cooling systems that lower the intake air temperature, thereby increasing the air density for more efficient combustion.

The introduction of turbocharging and charge air cooling enabled the diesel engine to develop more power at low engine speed, which effectively increased the engine operating speed range. A major step was then the introduction of the "high torque rise" diesel engine in the mid 1960s. The high torque rise concept offered excellent driveability characteristics by developing a relatively constant level of power over a wider range of engine speeds.

Starting in the early 1970s, which marked the beginning of an energy-conscious era in North America, the emphasis in the trucking industry shifted from power and speed to fuel economy. As pressures from escalating fuel prices mounted, industry concerns were compounded by the introduction of stricter emission control regulations. These two forces, with conflicting demands, have together brought about many changes in the trucking industry over the last ten years. Engine manufacturers have been under increasing pressure to improve the thermal efficiency, reduce mechanical friction, and limit parasitic losses, in order to improve fuel economy and, at the same time, reduce emissions.

A new line of economy engines, with lower rated engine speeds, were introduced in the mid 1970s. The basic concept is to limit the maximum engine speed and force the driver to operate at lower, more fuel-efficient engine speeds. These low rpm engines are rated between 1600 rpm and 1800 rpm, while the conventional engines are generally rated in the 2100 rpm range. The low rpm economy engines have found increasing acceptance in fleet operations as a means of controlling road speed and maximizing fuel economy, thereby reducing linehaul costs.

Since the early 1970s, higher efficiency turbochargers and improved charge air cooling systems have helped to increase power at low engine speeds. More efficient fuel injection systems, combined with other design improvements, have resulted in substantial thermal efficiency improvements. Considerable progress has also been made in the reduction of parasitic energy losses. Design improvements to the lube oil pump and water pump have resulted in lower pumping losses. Demand-actuated fan drive systems, commonly referred to as fan clutches, were introduced in order to engage the cooling fan only when required.

Engine manufacturers have also made a number of design improvements aimed at reducing gaseous emission levels. Improved charge air cooling systems have led to lower intake air temperatures, thereby reducing combustion temperatures. This has reduced the formation of harmful nitrogen oxides, allowing injection timing to be advanced for improved combustion efficiency. The increased air density, resulting from lower charge air temperatures, combined with higher efficiency turbochargers and higher fuel injection pressures, has also reduced hydrocarbon emissions through improved combustion efficiency.

Increasing fuel prices have also put pressure on manufacturers to improve tractor and trailer design. Aerodynamic drag and rolling resistance account for roughly 90% of the total resistive force which the linehaul vehicle's engine must overcome at typical highway speeds. Thus, reduction of these forces results in substantial fuel economy improvements.

Most efforts to date have concentrated on reducing aerodynamic drag on the forward-facing surfaces, which account for about 60% of the air resistance. A properly mounted wind deflector, which is now available on the market for as little as $500, can reduce aerodynamic drag by as much as 15%. Trailer forebody fairings provide similar drag reduction and have the advantage of not requiring adjustment for performance, while cab-mounted roof fairings generally achieve greater drag reduction than wind deflectors. Other add-on devices to reduce aerodynamic drag, such as tractor and trailer skirts, are still in the experimental stage and are expected to be on the market within the next five to ten years.

In recent years, considerable research has been directed towards the development of new tire designs, construction techniques and materials to reduce rolling resistance and increase tire life. In terms of rolling resistance, radial ply tires offer an advantage of up to 30% over standard bias ply tires, and this translates to fuel savings of roughly 10%-15%. These tires have been on the market in Canada for more than ten years, and the tire manufacturers estimate that 70%-80% of the linehaul tractor-trailer units now operate on radial tires. The practice of replacing dual tires with a wide single (super single) has been gaining popularity in the long-haul market, since these tires provide up to 10% better tread mileage and 8%-9% fuel savings over conventional dual radials. Low-profile radials provide fuel savings of up to 4% over conventional tires. In addition, they result in an increase in the tire life. Eventually, these tires are expected to replace standard radials.

The introduction of new lightweight materials to various truck components continues to offer opportunities to reduce vehicle weight. Over the last few years, aluminum and, to some extent, fiberglass have been used to replace various steel components. Although vehicle tare weight is not as important a factor as rolling resistance or aerodynamic drag (since payload counts for the bulk of the vehicle combination weight), further improvements in this area are anticipated over the next ten years.

With this background on both engine and vehicle-related improvements in the last ten to twenty years, the more detailed analyses of truck technology in Chapters 5 and 6 attempt to identify those improvements that can be anticipated in the next ten years. The cost implications of these improvements are assessed, and impacts on linehaul unit costs are estimated.

In recent years, a variety of new developments aimed at improving fleet efficiency and reducing operating costs have become available to the trucking industry. New maintenance procedures have resulted both from the requirements of new engine and vehicle technology, and in response to the desire to improve the durability and reduce the maintenance of heavy-duty trucks. Advances in information technology have provided opportunities for improved operational planning and fleet management. To provide an overview of the potential of operational improvements, recent developments are briefly discussed in Chapter 7.

Chapter 2

REGULATION OF FOR-HIRE TRUCKING

All aspects of commerce in Canada are affected in one way or another by government regulation (for example, building codes, labour legislation, vehicle standards, emission controls, and traffic laws). This chapter focuses specifically on what is commonly referred to as economic regulation or, sometimes, direct regulation.

It is difficult to provide a precise definition of what constitutes economic regulation in a given sphere of business activity. For the purposes of this study, economic regulation in the trucking industry is loosely defined to include federal and provincial statutes, regulations, and practices that control the conduct of commerce in the industry.

In the next section, an overview of the regulatory system is provided, emphasizing differences between statutory powers given to the regulatory authorities, and the actual practice of economic regulation in the trucking industry. Changes in the regulatory system are then examined by first reviewing the regulatory reform activities across the country, and then assessing their potential impacts on the industry.

2.1 Overview of Current Regulations

Control Mechanisms

There are three basic mechanisms for economic regulation in Canada. The first is control over entry, the mechanism whereby individuals or firms are authorized to engage in for-hire trucking. Situations where entry to the trucking industry requires a licence that is granted solely on the basis of fitness tests, such as meeting insurance requirements, satisfying residency requirements, or obtaining vehicle safety permits, are excluded from the scope of economic regulation. Economic regulation is said to exist only when entry to the industry is controlled for reasons other than just fitness.

The second mechanism, control over service, includes controls on the nature, type, and/or quality of service provided by licensed carriers. In general, such regulations control the areas or routes which may be serviced, the equipment which may be used, the commodities that may be carried, and even the shippers that may be served. The scope of economic regulation in this context, however, does not include such government regulations as vehicle weight and dimension regulations (which are addressed separately in the next chapter), truck route bylaws, operating period restrictions such as Sunday trucking, and insurance requirements.

Control over rates is the third mechanism. Government control over trucking rates is an important aspect of economic regulation. However, for the purposes of this study, economic regulation does not include the general controls, for example, anti-inflation measures such as the current "6 and 5" policy, or the broad controls imposed by legislation such as the Combines Investigation Act.

Statutory Powers

There are various federal statutes which affect the regulation of trucking, the Motor Vehicle Transport Act being the most relevant. This act authorizes the provinces to regulate extraprovincial trucking operations in a manner similar to their regulation of intraprovincial operations. Twelve provincial acts (or ordinances) constitute the primary mechanism for the economic regulation of the trucking industry. In all twelve jurisdictions, specific agencies (boards or commissions) have been set up to exercise the powers provided by the acts, although in most cases other government departments are also involved.

In all twelve jurisdictions, entry to the for-hire trucking industry is controlled through a licensing mechanism. Provincial regulatory agencies hold the power to grant, cancel, and control the transfer of licences, as well as to require licence holders to exercise the authority granted by their licences. In general, licences are granted or refused on the basis of "public interest, need, or convenience." The statutory guidance given to the regulatory agencies varies considerably from one jurisdiction to another. In some jurisdictions no clear statutory criteria are given to the regulatory agencies; in others, detailed tests must be applied; while in still others, a body of jurisprudence has been established.

The powers available to control service in each of the provinces are too complex to summarize succinctly. In general, however, it should be noted that once an individual or firm is licensed, the regulatory agencies have the authority to control almost every aspect of the service provided (e.g., equipment to be used, frequency, commodities, routes, shipment sizes, and conditions of carriage). The two most common means by which regulatory agencies control service is through the designation of licence classes, and through the particular terms and conditions specified on individual licences.

The power to control the rates of licensed carriers also varies substantially from one province to another. Under the existing statutes, some provinces have the authority to set rates, or at least to require that rates be filed and approved. Other provinces have only the power to require that rates be filed. The province of Alberta has no general powers over trucking rates, but under the existing statutes can still regulate tariff bureaus.

Enforcement

As noted above, all twelve jurisdictions actively regulate entry to the for-hire trucking industry by requiring licences or operating authorities. However, ten of these twelve jurisdictions make significant exemptions. Generally, these exemptions are for local or urban for-hire trucking, the for-hire trucking of unprocessed agricultural commodities (often only for the primary movements) and other unprocessed resource commodities (forestry, mining, fishing), and "dump-type" commodities (often when hauled for government construction projects). The two jurisdictions not involved in these types of exemptions are Quebec and Alberta. Quebec only makes significant exemptions for publicly owned organizations, while Alberta does not make exemptions in the application of statutory controls.

In addition to these specific exemptions, some jurisdictions apply less stringent controls to certain segments of the for-hire trucking industry. Licences are still required on these "less-regulated" segments of the industry, but both the tests used in the granting of a licence and the conditions attached to the licence tend to be less rigorous than those for the industry as a whole. Two notable jurisdictions in this regard are Ontario and Manitoba.

In comparing the entry control powers exercised in different provinces, it should be noted that the criteria used in the granting of licences vary from one province to another. In all cases the granting of licences appears to be subject to a public interest test. However, in some instances, the test is merely a formality, or else is a simple fitness test that must be met by the applicant. Most notable in this respect is Alberta where the granting of intraprovincial operating authorities is so routine that the literature generally refers to intraprovincial trucking in Alberta as unregulated.

It should be noted that it is not the requirement to be licensed per se that affects "real" economic regulation. Rather, it is the manner in which the "public interest test" is applied that dictates how regulatory agencies control entry into the for-hire trucking industry. However, there are only limited data available on the application of public interest tests in different provinces, and the effectiveness of these tests can therefore only be assessed qualitatively, based on past experience.

There is also a critical shortage of documented information on the exercise of control over the services which may be provided by a licensed carrier. It is difficult to assess how the powers exercised in practice compare with the statutory powers granted to the regulatory agencies. All jurisdictions exercise some control through measures such as licensed classes and the terms and conditions attached to individual operating authorities. However, the regulatory agencies in most jurisdictions have further powers which are probably never exercised. These include restrictions on the frequency of service, the common carrier obligation and drivers' hours of work.

Although some provinces exercise their power to regulate rates in specific circumstances, it would be incorrect to suggest that the provinces with these statutory powers are active rate regulators. In most cases, significant exemptions are made from licensing requirements (and therefore from rate regulation). Even in cases where authority is exercised, the general regulatory approach seems to be one of watchful indifference rather than active intervention.

One exception is perhaps Newfoundland, where both intraprovincial and extraprovincial trucking rates are actively regulated. Quebec is also characterized as an active regulator of most intraprovincial and extraprovincial rates, but compliance is so low (Boucher 1980) that, in practice, trucking rates appear to be virtually unregulated. In the past, Saskatchewan was an active regulator of some intraprovincial rates (although a large segment of the industry was exempt from rate regulation), but the more recent practice of maximum rate schedules permits a great deal of freedom in the setting of rates. In both Manitoba and British Columbia some intraprovincial rates, particularly general freight, are regulated.

In summary, all jurisdictions use considerable discretion in exercising their statutory powers to regulate for-hire trucking. In most cases there are certain barriers to entry, but it would be misleading to conclude that most provinces effectively regulate entry to for-hire trucking according to explicit policies. In the case of control over service, practices vary considerably from one province to another, but as a general rule, none of the provinces use the full range of their existing statutory powers. Some provinces do not have the statutory power to approve, fix or prescribe rates, and where there is effective power to regulate rates, controls are not always exercised.

2.2 Recent Trends and Pressures for Change

The existing regulatory systems governing the motor carrier industry are under review in almost every province in Canada. Although it is difficult to forecast the outcome of this process with any degree of precision, a number of factors that may influence the thinking of both government and industry officials across the country can be identified. It is important to note these before examining the review activities in each of the provinces.

Influential Factors

The experience of deregulation in most spheres of transportation activity in the United States is of immediate relevance. At the present time, it is not clear whether the U.S. experience is producing more ammunition for those who favour deregulation in Canada or for those who oppose it. It should be noted, however, that Canadian institutions have displayed a considerable reluctance to change, and are not likely to follow the experience of their counterparts in the U.S. as quickly as some may suggest. Nevertheless, as long as the turmoil continues in the U.S., regulatory reform in Canada is likely to remain a popular topic on policymakers' agenda.

Independent of specific developments in the U.S. transport sector, there is a general move towards a reduction of government interference in the marketplace. Although this is more evident in the broad policy statements made by various provincial governments than in actual legislative actions, these political trends are likely to continue and will no doubt influence the outcome of ongoing provincial reviews.

Major policy studies in Canada have generated a tremendous amount of information on, and interest in, regulatory problems in the transport sector. These include studies conducted by the Economic Council of Canada and by a federal interdepartmental group which included Transport Canada, the CTC, and Consumer and Corporate Affairs. While some observers of this work would correctly claim that all of this intellectual activity has been less than completely successful in demonstrating the effects of regulatory change, the work has fuelled the regulatory debate in favour of deregulation. The results of these studies will presumably sway provincial efforts towards relaxing regulation.

Another important factor is the activities of the Canadian Conference of Motor Transport Administrators (CCMTA). The primary concern of the CCMTA has been the reform and clarification of interprovincial differences in the mechanisms of regulation rather than the broader issue of regulation versus deregulation. This has raised some fundamental questions about the effectiveness of the current practice of economic regulation, and is likely to encourage movement toward a reduction in regulation.

Finally, there are unresolved federal policy issues that may have some bearing on the question of where the practice of motor carrier regulation is heading. The whole issue of the Combines Investigation Act and the status of tariff bureaus (or collective rate making) will undoubtedly influence how the provinces move to change their position on rate regulation.

Against this background, provincial activity in the review of regulations is discussed below. The relevant historical background is provided in each case to shed further light on the current situation.

Regulatory Review in the Atlantic Provinces

In Newfoundland, the trucking industry was effectively unregulated between the completion of the Trans-Canada Highway in 1965 and the proclamation of the Motor Carrier Act in 1968. It appears that the strict rate regulation that prevails now did not begin until the mid 1970s. A commission has been established to examine trucking regulation, but its terms of reference have yet to be defined.

In Prince Edward Island, the existing regulatory framework has been in place since the mid 1950s, and there are no formal plans to alter the regulatory system at the present time. It is understood, however, that the Public

Utilities Commission is considering some changes and would be prepared to follow the lead of any Canada-wide changes proposed by a CCMTA Symposium.

The existing regulatory framework in Nova Scotia has been in place for several decades, and has undergone only a few minor amendments. A committee, consisting of members of the Board of Commissioners of Public Utilities, the legislature, the trucking industry, and consultants, recently prepared a report suggesting changes to the Motor Carrier Act.

In New Brunswick, the regulatory system has been in place for a number of decades, and there are no definite plans for any major revisions to the existing statutes. As part of a more general legislative review process, some changes to the Motor Carrier Act are said to be under review.

Regulatory Review in the Central Provinces

The Quebec regulatory process was revised in 1972 under the new Transport Act, and there have been various amendments since then. In the spring of 1982, the Minister of Transport held a "consultation symposium on the highway transportation of goods," where commitments were made to regulatory change. Since that time, changes have been introduced affecting owner-operators, private trucking and the use of "contract licences." Contract licences, which are now much easier to obtain, permit a licensed carrier to work for a manufacturer located within 6.2 miles of a specially designated carrier-terminal. Owner-operators with only one truck are no longer prohibited from working directly for private shippers. As part of these recent changes, the scope of private trucking has been more clearly defined in the statutes. Goods must be owned by the owner of the vehicle, which must be driven by an employed driver and operated for the exclusive use of the owner. However, rules regarding long-term leases have been relaxed and vehicles leased for more than two years can be operated under the same conditions as owned vehicles.

The existing regulatory system in Ontario is the product of a long history of acts, amendments, commissions, and enquiries dating back to the 1920s. Some of the more significant historical events in the evolution of the existing system include the Chevrier Royal Commission in 1928 (recommending that the trucking industry be regulated), the establishment of a separate regulatory board (OHTB) for trucking and other means of highway transportation in 1955, and the introduction of a rate-filing system in 1963. In terms of regulatory experiments, the deregulation of the dump-truck industry between 1968 and 1976 is noteworthy.

The Select Committee of the Legislature on Highway Transportation of Goods was established in 1976, motivated by the government's desire to control what at that time was perceived to be a rapidly growing volume of illegal trucking activity. The Select Committee's mandate was quite broad, and was, in essence, to investigate the motor carrier industry with particular emphasis on regulation. Although other issues were examined, the committee's enquiry focused on the fundamental argument of whether to regulate or deregulate the industry. The primary thrust of its final 323 recommendations was the retention of economic regulation.

In 1978, the government introduced Bill 21, which tightened certain aspects of the regulatory system (enforcement powers), but which also contained several important deregulatory features such as commodity and area exemptions. This move was generally regarded as running counter to the Select Committee recommendations. Following a storm of protest, the bill was left to die in the legislature, but several months later, the government introduced a modified form of the bill. This also met with strong opposition from the trucking industry and was eventually withdrawn.

In June 1981 the government of Ontario established the Public Commercial Vehicles Act (PCVA) Review Committee. The purpose of the committee was to advise the Minister "on the principles that should form the foundation of new legislation which will regulate the trucking industry in Ontario over the next two or three decades." In November 1982, the committee published its interim report, which contained recommendations for significant relaxation of current regulatory practices.

In particular, the PCVA Review Committee recommended that the current test of public necessity and convenience, used to control entry to the Ontario for-hire trucking industry, be replaced with a more objective "fitness" test. The committee also recommended that current operating authorities be simplified--presumably resulting in their expansion--and that many aspects of the regulatory process be streamlined. The final report of the committee was tabled in the legislature in June 1983, and a PCVA Implementation Committee has been established to translate the Review Committee's recommendations into a set of specific regulations.

Regulatory Review in the Western Provinces

In Manitoba, there have been a number of modifications to the regulatory system over the years, but the basic tenets of the current regulatory environment can be traced back to the introduction of the Highway Traffic Act in 1930. Following this act, the first regulated tariff of tolls, or prescribed rates, came into effect in May 1931. In 1966 the regulatory legislation was completely rewritten, but the basic principles of the regulatory system remained essentially intact. Since that time, there have been only a few changes, the most important of which was the expansion of for-hire carriage activities that are exempt from regulation. Currently, a task force is conducting a wide-ranging review of Manitoba's regulatory system.

The existing regulatory system in Saskatchewan has been in place since 1939. Over the years there have been various amendments, reviews and studies, as well as significant shifts in regulatory practice (particularly in rate regulation). In December 1982, the minister responsible for the Highway Traffic Board in Saskatchewan circulated a white paper outlining proposals for updating and reorganizing the Vehicles Act. Some of the changes include the separation of vehicle registrations and operating authorities, modification of the definition of general merchandise, and new enforcement procedures.

As of 1975, Alberta was the only Canadian jurisdiction which did not effectively regulate intraprovincial for-hire trucking, although it did regulate entry to and service of extraprovincial for-hire trucking. In 1975, a select committee of the legislature was established to review trucking regulation. The committee's report in March 1977 recommended some tightening of intraprovincial entry controls, but stopped short of recommending any real public interest tests. Further, the committee recommended against rate regulation.

The new Motor Transport Act in Alberta came into effect in 1978, replacing the Public Service Vehicles Act. However, the new act did not change the prevailing regulatory philosophy in Alberta. It is understood that currently there is a process to streamline the regulatory procedures, but that no attempt is being made to introduce any significant changes to the existing regulatory system.

The current regulations in British Columbia have their origin in the Highways Act of 1930. In 1939, the Motor Carrier Act replaced the Highways Act as the primary legislation establishing a regulatory system for for-hire motor carriers in the province. Although there have been a series of amendments and changes in the regulations over time, there have been no significant shifts in the general form of the regulatory system since its inception.

Since 1970, there have been at least two internal reviews of the regulatory environment. In both cases, the resulting recommendations dealt with administrative and/or procedural matters. Both of these reviews recommended the selective relaxation of some regulatory practices (such as extension of exemptions, and greater reliance on rate filing), but neither resulted in any significant changes to the regulatory environment in British Columbia.

2.3 Expected Changes and Potential Impacts

In the four provinces that are nearing the mature stage of their review process (Nova Scotia, Quebec, Ontario, and Saskatchewan), no significant moves are being contemplated to disband the primary statutory powers that give rise to economic regulation. These provinces appear to be moving towards the reform of some regulatory mechanisms, and possibly (particularly in Quebec and Ontario) the selective relaxation of some aspects of motor carrier regulation. The real test as to whether this reform constitutes a move towards more or less regulation will be in how the regulatory agencies will choose to exercise their powers and how well the motor carrier industry will comply with the new rules and controls.

Central to the review and reform process currently taking place is the question of the enforceability of the present regulatory system. It is probably not a concern with the role of government in the marketplace, but rather problems with enforcement that initiate the process and influence the outcome of regulatory change. In the U.S. the broader political concerns and the conviction of some administrators have played a significant role in the deregulation of the transport sector. In Canada, the practical concerns with enforceability and with the financial health of the industry appear to be the more important factors guiding the reform process.

Thus, it would be incorrect to characterize the current review process in Canada as being primarily concerned with the broad issue of regulation versus deregulation. While the preoccupation with the deregulation debate leads to rhetorical statements by both industry and government, in practice the primary concern is the reform of existing regulatory procedures. The driving force behind the relaxation of certain regulations is the practical concern with enforceability rather than an inherent belief in the virtue of market forces in the trucking industry.

The net effect of the process of reforming and relaxing the current regulatory system may actually be to bring a greater proportion of for-hire motor carrier activity within the regulatory "net." By the admission of some of the provinces now reviewing their regulatory systems, there are aspects of the current regulations that are unenforceable, and there are significant segments of the motor carrier industry operating outside of the regulatory controls. If the regulatory system is reformed, a greater proportion of motor carrier activity may be brought under more effective, albeit a more relaxed form of control.

In the final analysis, the current review process may accomplish nothing more than previous attempts to modify regulatory practices, that is, a modernization of the regulatory programs to more or less reflect what has already occurred in the marketplace. The ongoing regulatory change may remove some statutory controls, but this is not likely to bring about the deregulation of for-hire trucking. The elimination of rate regulation may put an end to what is already an ineffective process of filing rates.

Similarly, more relaxed forms of entry tests (moving from public interest to fitness tests) may streamline existing practices, but will not necessarily have an immediate effect on the supply of for-hire trucking services. Even with the existing entry controls, there are definite signs of excess capacity in the industry, resulting in fierce rate competition. With the relaxation of entry controls, certain adjustments will undoubtedly take place, but such changes are not likely to have a significant impact on either costs or rates.

Chapter 3

PRIVATE TRUCKING AND OWNER-OPERATORS

While this study focuses primarily on for-hire trucking, there are a number of important developments in other segments of the trucking industry that might have impacts on the scope of for-hire trucking activity in the near future. These include regulatory changes that may affect the role and scope of private trucking, rapidly changing the role of owner-operators, and the emergence of independent trucking. This chapter provides an assessment of these developments and their potential impacts on for-hire trucking. In the following sections, existing regulations that govern trucking outside the company operations of for-hire carriers are examined, and newly emergent trends and business practices are reviewed. Finally, the potential impacts of these trends on truck operating costs are examined.

3.1 Overview of Current Regulations

Private Trucking

The original intent of the legislation regulating the trucking industry was to control for-hire trucking, and as a result, private trucking is only explicitly defined in the statutes of British Columbia. However, even in the absence of a clear statutory definition, it can be inferred, by considering the definition of for-hire trucking and the wording of the exemptions that apply in this context, that private trucking is the movement of goods where both the goods and the means of transportation are owned by the same person or firm, and where no compensation is paid for the transportation service. Although this can be used as a general definition for the "pure" case of private trucking, it is useful to note the differences in the provincial statutes from which this general definition is derived.

In Newfoundland, Prince Edward Island, and New Brunswick, private trucking is exempt from the legislation, and is defined to be "a vehicle which is used exclusively for the transportation of goods and chattels bona fide the property of the owner of the motor vehicle, or the person in whose name the vehicle is registered." In Nova Scotia, there is no explicit exemption for private trucking, but the legislation applies for "freight vehicles" which are defined as vehicles used to haul freight "for gain."

In Quebec, the regulatory legislation covers all "transporteurs." This does not include private truckers as long as company-owned vehicles and paid drivers are used. Private companies are allowed to use vehicles that are leased for more than two years and owner-operators who do not own more than one vehicle (but who, as discussed below, are licensed themselves). In Ontario, legislation explicitly applies to "transportation for compensation of goods of any other person," and accordingly excludes "pure" private trucking. In addition, the legislation allows for the granting of a "certificate of intercorporate exemption," permitting related corporations to operate commercial vehicles for the transportation of goods owned by any of them, even when compensatory charges are made.

The Manitoba legislation applies to all trucks, and a vehicle used in a private trucking capacity must have a special licence. Similarly, in Saskatchewan, regulations encompass all trucking activity. A person (or firm) wishing to transport his (its) own goods by truck is granted a registration certificate that allows the operation of vehicles in a private capacity. In the case of both Manitoba and Saskatchewan, the statutory requirements raise the question of whether or not private trucking is subject to economic regulation. In both cases, however, the granting of licences is so routine that it would be misleading to imply that the licensing requirement actually constitutes real entry control.

Private trucking in Alberta is defined implicitly through a number of provisions of the regulations promulgated under the Motor Transport Act. Private carriage covers those cases where the goods are owned by the registered owner of the vehicle, where the transportation of the goods is incidental to the regular business of the registered owner of the vehicle, and (under various conditions) where private carriage is deemed to exist with leased vehicles. The only jurisdiction where private trucking is explicitly defined is in British Columbia. A "private freight vehicle" is defined as any motor vehicle which is not otherwise classified as a for-hire vehicle and which is operated under the following conditions:

- the transportation of freight bona fide the property of the owner of the motor vehicle
- the transportation of freight associated with the trade occupation, or business of the owner of the vehicle where such transportation is incidental to such trade, occupation, or business
- the delivery or collection of freight sold or purchased, or agreed to be sold or purchased, or on hire by the owner of the motor vehicle, otherwise than as agent, in the course of a regular trade or established business of such owner.

Owner-Operators

The term "owner-operator" usually refers to an individual who owns a tractor and who usually works under the operating authority of a licensed for-hire carrier or for a private carrier. They are generally paid either a percentage of the rate obtained for their loads or a specified rate per kilometre. In addition to this common form of operation in both for-hire and private carriage, owner-operators in some parts of the country carry commodities in exempt for-hire situations, that is, they haul independently with no specific operating authority.

In some cases, the meaning of owner-operators is expanded to include "independent trucking" where an individual uses his own operating authority to work for someone else. In most cases, such independent operators work for freight brokers, but they can also contract to for-hire or private carriers.

Although there are variations in the types of arrangements permitted between owner-operators/independent truckers and those who provide the transportation service (i.e., for-hire carriers, private carriers, or freight brokers), all provinces allow this kind of activity in one way or another. In Quebec, for example, owner-operators are required to be licensed even if they are hauling freight under somebody else's operating authority. Similarly, in British Columbia, owner-operators are granted their own licences. In other jurisdictions, owner-operators register their vehicles in the name of the firm for which they work, and are deemed to be employees. In some jurisdictions, most notably Ontario, the legal status of the arrangements that take place between owner-operators and carriers with regard to operating authorities is unclear.

As fundamental as these differences may be in certain cases, all jurisdictions in Canada have found ways to accommodate the use of owner-operators within their regulatory systems. In reviewing the regulatory controls on owner-operators it should be recognized that the increasing use of, and in some cases the changing role of owner-operators presents problems in the context of the existing statutes. It is useful to view the intent of the legislation in terms of the two "pure" trucking situations, "for-hire" and "private" trucking. The original legislation did not generally consider any middle ground between these two "pure" cases, such as, an "owner-operator" who owns his own vehicles and enters into some form of commercial arrangement with a carrier holding an operating authority; a "transportation broker" who arranges transportation services but neither owns any vehicles, nor accepts any transportation liability (i.e., the conditions of carriage on a bill of lading); or a "freight forwarder" who provides a transportation service, accepts liability, and may even own local pick-up and delivery vehicles. These "impure" situations create problems for the existing regulatory mechanisms.

3.2 Recent Trends and Pressures for Change

Scope of Private Trucking

Although the "pure" case of private trucking can be defined quite easily, the concept of ownership, both of the goods and the vehicle, always presents problems. In the case of ownership of goods, the major problems often arise due to intercorporate relationships. For example, a large meat-packer in Manitoba has been required to hold a for-hire licence for some time because the corporate entity owning the meat-packing business also owns a number of other enterprises. In Ontario, this may not have been necessary if a "certificate of intercorporate exemption" had been obtained.

A related problem concerns the issue of "compensation for transportation services" in the case where the goods are still in the possession of the same company. A fast food business in Newfoundland, for example, was required to apply for (and received) a for-hire licence because the charge for the delivery of phone-in orders was deemed to constitute a transportation service "for hire, gain, or rewards" under the provincial act. A similar example involves a large oil company in Nova Scotia which held a for-hire licence for the delivery of its petroleum products from its refinery to its agent-owned retail outlets. If the delivery charge was included in the product price, the company should not have been required to hold a for-hire licence.

The definition of vehicle ownership varies from one province to another and is often a source of controversy. Some provinces accept the registration of the vehicle in the name of the company which owns the goods as a sufficient condition for private trucking. This may include a lessee, but in New Brunswick, for example, the lease agreement has to be approved by the regulatory agency. In Quebec, as a result of a very recent change in regulation, a lease for a period of more than two years provides sufficient grounds for the vehicle to be treated as company owned.

Given these problems with the definition of private trucking in practice, certain regulatory changes can be expected to clarify some of the ambiguities surrounding private trucking. For example, there may be continuing pressure to accept vehicle registration in the company's name as a sufficient condition for private carriage, irrespective of the actual ownership of the vehicle. Despite pressure to liberalize the scope of for-hire carriage, however, it has been suggested that private trucking should be brought more firmly within the regulatory mechanisms. This has been the case in Saskatchewan, where the regulatory authorities currently have the statutory powers to control entry to private trucking but only rarely exercise any real control (which is generally directed at extraprovincial private trucking.)

As noted above, the most recent changes to legislation regulating private trucking were introduced in Quebec, permitting the use of owner-operators with no more than one vehicle. The intent of the new legislation was to clearly define the limits of private trucking rather than to liberalize its scope. Intercorporate trucking is another area where pressures for further relaxation may be felt. Although provincial authorities may choose to follow the Ontario experience in this regard, there are no apparent moves in this direction. In general, it can be said that even in the context of the intense reform activity concerning for-hire trucking discussed in the previous chapter, none of the provinces appear to be taking serious steps to reform and/or relax the scope of private trucking.

Another issue which is often raised in the context of the ongoing regulatory debate is the potential use of private truck fleets for the purpose of for-hire carriage. Those in favour of deregulation argue that empty backhauls in private trucking lead to inefficient resource utilization which can be corrected by permitting private fleets to engage in for-hire carriage. This could be done either by issuing special permits or by removing all entry controls to private carriage which de facto will accomplish the same result.

It is very difficult to address this issue since very little is known about the extent of empty backhauling in private carriage. Some would argue that even if there was available capacity, private companies could not engage in the business of for-hire carriage without the help of a third party such as a freight broker or forwarder. If this were to become a new trend in the trucking industry, there may be some noteworthy impacts, and these are discussed in the next section.

Owner-Operators in For-Hire Trucking

In the past few years, established for-hire carriers have increased their use of owner-operators. The reasons are basically twofold. First, owner-operators are generally willing to work under more flexible rules and conditions and, in some instances, for lower equivalent hourly wages than union drivers. Carriers use owner-operators as a countervailing force to their unions or as a way around restrictive collective agreements. This often results in considerable labour cost savings.

Second, owner-operators offer an alternative source of capital to the industry. Trucking companies tend to be privately owned and have been reluctant or unable to become publicly traded companies. This pattern of ownership has stifled their ability to raise capital in financial markets and instead, has encouraged them to turn to alternative sources like owner-operators.

The use of owner-operators has also become very common in private trucking. Unlike the case of for-hire carriage, however, this practice poses some regulatory problems. An owner-operator can simply register his vehicle in a for-hire carrier's name and operate under that carrier's authority. However, in the case of private carriage, he may confront the problems discussed above concerning the definition of vehicle ownership. In British Columbia, for example, private carriage can be conducted using vehicles registered in the name of (but not owned by) the company which owns the goods, unless the driver himself holds the ownership of the vehicle. This has recently caused controversy in the case of a group of owner-operators domiciled in Alberta and hauling goods to and from British Columbia for a co-operative. Although they are deemed to be private truckers in Alberta, they were required to obtain for-hire licences in British Columbia. In Quebec, on the other hand, in addition to the general requirement that all owner-operators hold a valid licence, owner-operators with more than one vehicle in their ownership cannot work for private fleets.

As both the for-hire and private fleets rely more heavily on owner-operators, regulators will be under increasing pressure to remove statutory obstacles such as that of the distinction between "ownership" and "registration." Some provinces may follow the Quebec experience in licensing owner-operators, but these licences would be quite distinct from operating authorities granted to for-hire carriers, and are most likely to be issued routinely on the basis of a simple "fitness" test.

Another significant trend in the industry is the increasing role of owner-operators as independent truckers. As noted previously, it has become common practice to use owner-operators to haul exempt commodities (without an operating authority). If exempt commodity situations were to be expanded, owner-operators could move into these markets and operate as independent truckers. In this capacity, however, a trucker is likely to operate through freight brokers since he would not be able to undertake the necessary marketing and terminal operations himself. Moreover, few major shippers would want to deal with numerous independent truckers and, therefore, would rely on the services of freight brokers to organize truckers for them. Thus, the freight broker would play the same role for the independent trucker that the for-hire carrier plays for an owner-operator.

Freight brokers have been around for some time in parts of Western Canada and a number of brokers have recently entered the Ontario market as well. They serve small for-hire fleets (with operating authorities) that find it difficult to generate freight themselves, and owner-operators that haul exempt commodities without an authority, especially in Western Canada. The scope of freight brokerage activities may continue to expand since small operators find it difficult to compete with large carriers, particularly in LTL (less than truckload) markets.

If market entry tests are relaxed (e.g., the inception of a fitness test as a result of the PCVA Review Committee Recommendations in Ontario) allowing owner-operators, either individually or in groups, to obtain operating authorities, the role of the freight brokers will naturally expand further. As suggested in the previous chapter, radical deregulation of the for-hire trucking industry, along the lines of the Motor Carrier Act of 1980 in the U.S., is not likely to occur in Canada, except in pockets such as

Alberta where intraprovincial operating authorities are granted quite routinely. In any event, however, freight brokers and independent truckers are likely to play an increasingly important role in the Canadian trucking scene even though such developments may not occur as rapidly nor to the same extent as has been observed in the U.S. following deregulation.

3.3 Expected Changes and Potential Impacts

Private Trucking

As referred to earlier, allowing private companies to pick up general freight on their empty backhauls may have some potential implications for for-hire trucking. In essence, these companies would be allowed to generate transportation revenue on their backhauls that would offset their operating costs. In order to fully understand the implications of opening up the general freight market to private truckers, it is important to understand the reasons why private companies transport their own goods rather than contracting out to for-hire carriers.

There is no reason to expect the linehaul costs of a private company to be significantly different from those of a for-hire carrier. Thus, if for-hire carriers can generate freight for their backhaul to balance their traffic, they should be able to offer rates that are lower than the costs faced by private companies who ship goods one way but return empty. This reasoning leads to the conclusion that companies would engage in private trucking if for-hire rates were considerably higher than their own costs, or if for-hire carriers were unable to pick up freight on their backhaul due to extremely unbalanced traffic conditions on that particular lane (and thus, were in no position to offer rates that were lower than what it would cost the company to ship its goods privately). Alternatively, private companies may be willing to pay a "premium" for transporting their own goods in order to have greater flexibility and control over service levels.

The first condition is highly unlikely since there is sufficient competition in the for-hire trucking industry in Canada to prevent any one carrier or group of carriers, from charging excessive rates. The second condition is indeed a possibility, but if this were the case, private companies entering the for-hire market would not affect rates or costs, since they too would be unable to generate backhaul traffic. In any event, this situation is unlikely to occur in the high density routes that are of particular concern to this study, with the exception, perhaps, of the Toronto/Halifax route where traffic seems to be the most unbalanced. In the third case where flexibility is the key factor in choosing private over for-hire trucking, it is unlikely that a company would be willing to forego any of that flexibility in order to generate backhaul revenue to offset part of its operating costs by engaging in for-hire carriage.

From these observations it could be inferred that removal of the entry barriers that currently prevent private trucking fleets from carrying general freight is unlikely to have major impacts on either the costs or rates that currently prevail in the industry. If the current for-hire rates are sufficiently competitive in the high density corridors that are of concern to this study, private companies transport their own goods because either their own intra-company traffic is fairly balanced (thus, their unit operating costs are not different than for-hire rates), or they are willing to pay a premium for greater flexibility (which they are not likely to forego for the sake of generating additional revenue).

Owner-Operators

It is likely that future regulatory change will affect the commercial relationship between owner-operators and their "employers." However, nothing currently known about the current review process suggests that any such changes will significantly affect a carrier's ability to employ owner-operators. In addition, in clarifying the legal status of owner-operators or, in recognizing the growing trend to use them, some of the probable changes will actually make it easier to employ owner-operators. An example of this would be the clarification of the vehicle ownership issue.

In at least two jurisdictions it appears that future regulatory change will enhance the status of owner-operators. In Quebec a commitment has been made to broaden the authorities of owner-operators. In Ontario, the PCVA Review Committee has suggested an adjustment to the concept of an owner-operator in order to allow them to lease themselves to carriers without being required to transfer their vehicle ownership. All of this suggests that the trend of increasing use of owner-operators will continue, and that regulatory institutions are likely to accommodate the process.

As indicated above, the role of the owner-operator is likely to expand both in for-hire and private trucking. Under highly competitive conditions, owner-operators seem to be willing to work for lower compensation for their time than union drivers, and to accept lower returns on their investment than the prevailing rates in capital markets. All these factors tend to lower linehaul operating costs.

An attempt is made in Table 3.1 to compare the linehaul costs of using an owner-operator with those of a comparable company-owned vehicle driven by a union driver. The most substantial savings are due to lower driver costs, which are now in the order of 24¢/mi. compared with average company driver costs of about 37¢/mi. in Eastern Canada and 45¢/mi. in Western Canada (see Appendix A for details). Thus, on the average, owner-operators offer a cost advantage of about 10%-16% due to lower driver costs alone.

Savings in terms of capital-related costs are much smaller, but more difficult to assess since they depend on the debt-to-equity ratio as well as return on equity, both of which may vary considerably in practice. In the extreme case, savings can be in the order of 2.0%-2.5% if there is no borrowing involved, and the objective is to recover the original capital outlay in the lifetime of the vehicle, with no further return on that original capital. Under such conditions, the net return the owner-operator accepts for his investment is limited to the compensation he receives for his labour. If, on the other hand, all the capital is borrowed at prevailing interest rates, unit costs may be 0.7%-1.5% higher than costs of for-hire fleets. The variation in capital costs is due to different vehicle utilization in Eastern and Western Canada (100,000 mi. and 130,000 mi. per year, respectively).

Table 3.1

Cost Savings from Owner-Operators

	% Savings	
	Eastern Canada	Western Canada
Driver Wages	10.0	16.0
Cost of Capital 1	2.5	2.0
2	(-1.5)	(-0.7)
Cost of Equipment 1	-1.0	-0.9
2	(-1.6)	(-1.4)
Total	11.5 (6.9)	17.1 (13.9)

1 Strict capital recovery with no real return.

2 Borrowed capital at market interest rates.

Part of these savings may be offset by equipment costs which tend to be higher for owner-operators who do not qualify for the large fleet discounts that are offered to established companies in the industry. When all these factors are taken into account, unit linehaul costs of owner-operators can be 12%-17% lower than the average costs for company-owned vehicles driven by union drivers.

In practice, it has been observed that some owner-operators work for rates below their average operating costs. This has in turn lead to charges that such owner-operators are not capable of calculating their own costs, or that they are simply irrational. Although there may be a few operators with poor "business sense," it should not be overlooked that certain market conditions can temporarily force even the most rational owner-operator to work for rates that do not cover his average operating costs.

If market conditions, such as a recession or an over-supply of owner-operators, are such that owner-operators cannot command rates high enough to cover their fully allocated costs (including the appropriate capital-related charges), they may well work for a rate that exceeds their avoidable costs (i.e., fuel, maintenance, tires) and covers at least part, but not necessarily all, of the additional costs that are fixed as long as they own the vehicle (e.g., insurance, licence fees, loan payments). They could choose to do this in anticipation of improved business conditions that may allow them to cover their interim losses. Alternatively, they may find themselves in a position where rather than dissolving their operation (selling their truck) it is better to continue to operate even if they could never recover their entire capital outlay. They may then choose to fold their business at the end of the useful life of their vehicle.

Thus, in practice, market conditions may cause owner-operator rates to fall below fully allocated average costs, but not below strictly avoidable costs. Under these extreme conditions, linehaul costs using owner-operators may be 50%-55% lower than with company-owned vehicles driven by union drivers. To suggest that rates could continue to prevail at these suppressed levels in the long run, however, would necessarily imply that owner-operators would be willing to continuously pump capital into their operation with no hope of recovering it. It clearly is unrealistic to suggest that this scenario could characterize the owner-operators' role in the for-hire trucking industry in the long run. The only sustainable advantages owner-operators could continue to offer to the industry are lower labour costs and a supply of capital with modest return expectations. These are reflected in the savings shown in Table 3.1.

In conclusion, as owner-operators replace company vehicles driven by union drivers, average operating costs in the industry will tend to decline towards the levels shown in Table 3.1. These costs would also be representative of the independent truckers who operate through freight brokers. While the linehaul costs would be the same, total freight charges may be somewhat higher if freight brokers incur higher handling, marketing, administration and related costs than the typical for-hire carrier. However, the currently available cost information does not even permit speculation on this matter at this stage.

Chapter 4

WEIGHT AND DIMENSION REGULATIONS

Vehicle weight and dimension regulations are a complex set of rules that govern the maximum permissible size and weight of vehicles. They control the width, height and length of vehicles; vehicle combinations; axle weights; tire size and pressure; gross combination weights; and in some instances, minimum permissible power-to-weight ratios for large vehicles.

This chapter is concerned primarily with regulations that govern the use of large vehicle combinations, that is, tractor-trailer combinations with five or more axles. The following section provides an overview of the current regulatory environment and includes a discussion of the major regulatory changes that have occurred in the past decade. Current activities and issues, concerned primarily with the use of longer and heavier combinations, are outlined, followed by an examination of the impact of potential regulatory changes.

4.1 Overview of Current Regulations

Background

Vehicle weight and dimension regulations are established pursuant to various highway-related statutes administered by highway departments in each of the provinces and the territories. In certain provinces, municipal governments also promulgate rules governing the size and weight of vehicles permitted to use roadways under their jurisdication. Other provincial agencies concerned with transport policy and planning are also frequently involved in the regulatory process.

The federal government is directly involved in weight and dimension regulation for roads under their jurisdiction (those in national parks), as well as being involved elsewhere through participation in various funding programs. The indirect federal involvement has been particularly significant in the development of the Trans-Canada Highway and the financing of highway strengthening projects in the Prairie and Atlantic regions.

To appreciate the existing weight and dimension regulations in Canada, and how they are likely to change over time, it is useful to review recent developments which have led to their current status.

In early 1974, permissible vehicle dimensions were normalized to an overall combination length of 65 ft., a maximum width of 8.5 ft. and a maximum height of 13.5 ft. Weight limits were not standardized at that time, and gross combination weights (GCW) ranged from 75,000 lb. in the Prairie provinces to 134,000 lb. in Ontario. In addition to variations in the basic weight limits, different jurisdictions had varying requirements for elements such as axle spacings and tire pressure, which had to be complied with in order to operate at the permitted weights.

The major implication of the situation in 1974 was that it was impossible to make effective use of double trailer combinations on routes involving either the Prairie region or Nova Scotia. Payloads were limited to 39,700 lb.-40,000 lb. in the Prairie region and 44,000 lb.-50,700 lb. in Nova Scotia. Since 1974, several major changes and a number of relatively minor modifications have been made to the vehicle weight and dimension regulations in Canada. The major changes are discussed below.

The 1974-79 Federal-Provincial Western Canada Highway Strengthening Program designated a primary highway network in the Prairies. On primary highways, allowable axle weights were raised to 19,900 lb. and 35,000 lb. for single and tandem axles respectively. In addition, the gross combination weight limit was increased to 110,250 lb. As a result, standard five-axle tractor semi-trailer combinations could be operated with a 79,400 lb. GCW (compared with the previous maximum of 75,000 lb.) and A- and B-train double-trailer combinations with six to eight axles could be used effectively on major highways with gross combination weights of up to 110,250 lb. The use of these A- and B-train double-trailer combinations resulted in a payload capacity that was nearly double that of the previously permitted vehicles.

The principal objective of the 1978 Federal-Provincial Atlantic Provinces Highway Strengthening Program was to permit the use of 110,250 lb. gross combination weight units on major highways throughout the Atlantic region. This allowed doubles to be used effectively to and from Nova Scotia. Phase II of the program began in 1982. At this stage, the implications for weight and dimension regulation in the Atlantic region are unclear. One could speculate, however, that the program may justify further relaxation of weight limits.

In 1982, on their own initiative, the Prairie provinces increased the maximum permissible GCW on primary highways. The increase was 7% (to 118,000 lb.) in Alberta and Saskatchewan and 13% in Manitoba (to 124,600 lb.). In addition, the maximum GCW potential of double-trailer combinations (based on axle-load limits) on most non-primary highways was raised by as much as 45% to 108,000 lb. As a result, the full GCW could be achieved with 7-axle combinations in Alberta and Saskatchewan and with 8-axle combinations in Manitoba. The change allowed the effective use of doubles on highways that were not part of the primary network. The prior limit of 75,000 lb. had not permitted the effective use of doubles on non-primary highways in the region.

Coupled with the above adjustments to weight limits, important increases in allowable combination lengths have also occurred in recent years. This has been particularly significant in Western Canada, where doubles can now be operated at lengths up to 75.5 ft. This permits the use of long wheel-base tractors with double-trailer combinations hauling relatively low density ("cube-out" rather than "weight-out") loads.

Current Regulations

A summary of the current weight and dimension regulations that apply to primary highways is provided in Table 4.1. At this stage, the major observations to be made about the existing regulatory environment are:

Table 4.1

Current Vehicle Weight and Dimension Regulations

		Nfld	PEI	NS	NB	Que	Ont	Man	Sask	Alta	BC	YT	NWT
WIDTH													
- maximum	(inches)	102.0	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.0	102.4	102.4	120.0
HEIGHT													
- maximum	(feet)	13.6	14.8	13.6	13.5	13.6	13.6	13.6	13.6	13.5	13.5	13.8	13.5
LENGTH													
- combinations - tractor & semi-trailer	"	68.9	65.6	68.9	65.6	68.9	68.9	65.6	65.6	65.5	65.6	72.2	80.0
- combinations - "doubles" (or trains)	"				68.9			75.5	75.5	75.5	75.5		
AXLE LOADS													
- front (steering)	('000 lb.)	19.9	20.0	19.9	19.9	18.8	22.0	12.0	12.0	16.0	20.0	22.0	
- single	"	20.0	20.0	19.9	19.9	22.0	22.0	20.0	20.0	20.0	20.0	22.0	18.0
- tandem-drive	"	37.0	37.5	37.5	37.5	38.6	42.0	35.0	35.0	37.0	37.5	42.0	
- tandem	"	37.0	40.0	39.7	39.7	20.0	42.0	35.0	35.0	37.0	37.5	42.0	
- triple (tri-axle)	"	45.0	59.8	59.5	59.5	66.0	63.0	35.0	35.0	37.0	57.5	63.0	
GROSS COMBINATION WEIGHT													
- tractor & semi - 5-axle	"	87.1	87.5	87.1	87.1	106.9	104.0	82.7	82.0	86.0	80.0	95.2	80.5
- tractor & semi - 6-axle	"	106.9	107.5	106.9	106.9	126.8	125.0	82.7	82.0	86.0	95.9	116.2	89.3
- A-train - 7-axle	"	X	X	110.2	X	126.8	140.0	122.8	118.0	118.0	127.2	X	116.8
- A-train - 8-axle	"	X	X	110.2	X	126.8	140.0	124.6	118.0	118.0	140.0	X	116.8
- B-train - 7-axle	"	115.7	118.0	110.2	125.0	126.8	140.0	118.0	118.0	118.0	124.6	139.6	116.8
- B-train - 8-axle	"	115.7	118.0	110.2	X	126.8	140.0	118.0	118.0	118.0	140.0	139.6	116.8

1. X indicates that a special permit is required.

Source: Bus and Truck Transport (August 1983), reprinted in Traffic Notes (November 1983).

- Double trailer combinations can now be used on the four lanes of concern to this study, although due to the nature of the traffic doubles are rarely used on the Halifax run.

- Prince Edward Island restricts overall combination length to 65.6 ft.; the other Eastern provinces and Ontario and Quebec permit lengths of 68.9 ft.; and the Western provinces allow lengths of 75.5 ft.

- There are no significant variations in height or width restrictions from the norm of a 13.6 ft. height limit and a 102.4 in. width limit. There are, however, important variations in length limits.

- There are no significant differences in single-axle weight limits across the country, with non-front single-axle limits ranging from 19,900 to 22,000 lb. There are, however, significant differences in front axle loadings in terms of the "theoretical" maximums that can be attained.

- There is significant variation in tandem-axle load limits: 37,500 lb.-39,700 lb. in the Atlantic region, 42,000 lb.-44,000 lb. in Ontario and Quebec, and 35,000 lb.-37,500 lb. in Western Canada.

- There are also important differences in triple-axle load limits. For example, in the Prairie provinces, allowable loadings on triple-axles are no higher than those on tandems. Moreover, in different provinces there are important variations in the definition of what constitutes triple-axles.

The differences in tandem-axle limits, coupled with the varying approaches used by different jurisdictions concerning axle spacing (particularly triple-axle groups) has created wide variations in GCW limits across the country and, in turn, in the payload capacity of various types of units. This can be illustrated clearly in a brief examination of typical configurations operating in the high density freight corridors in Canada. Two such configurations are:

- Tandem-tractor with 45-ft. tandem or tri-axle semitrailer
- Tandem-tractor with 27-ft. semi-trailer and full trailer (A-train), or two 27-ft. semi-trailers (B-train)

The highest GCW for tandem-tractor/semi-trailer combinations can be achieved in Quebec: 106,900 lb. with tandem-axle and 126,800 lb. with tri-axle trailers. However, since allowable loadings in Ontario are slightly lower than those in Quebec, the Ontario limits (104,000 lb. with tandem-axle and 125,000 lb. with tri-axle trailers) govern weights on the Montreal-Toronto lane. Regulations in the Atlantic provinces limit GCW on the Halifax route to 87,100 lb. and 106,900 lb. with tandem-axle and tri-axle trailers respectively.

The most restrictive axle loading limits in the country are in Saskatchewan and Manitoba, where the maximum GCW that can be achieved with tandem-tractor/semi-trailer combinations is limited to 82,000 lb. The same limit applies to both tandem-axle trailers and tri-axles. Although allowable axle loadings in British Columbia are higher (permitting GCWs of 87,000 lb. and 95,900 lb. with single-tandem semi-trailer and tri-axle semi-trailer combinations respectively) through shipments from Toronto to Vancouver must conform to the stricter regulations in the Prairie provinces.

The maximum GCW that can be achieved with tandem-tractor double trailer combinations are 110,250; 126,800; 124,600 and 118,000 lb. on the Toronto-Halifax, Toronto-Montreal, Toronto-Winnipeg and Toronto-Vancouver lanes respectively. The Toronto-Vancouver run is again governed by Prairie (Saskatchewan and Alberta) limits.

The maximum achievable gross combination weights presented here are the theoretical maximum loadings. However, these theoretical maximums are difficult to achieve in practice. For example, a GCW of

104,000 lb. on a tandem-tractor/tandem-axle semi-trailer combination (the maximum on the Toronto-Montreal route) implies a loading of 19,900 lb.-22,000 lb. on the front axle and 42,000 lb. on both the drive and semi-trailer tandem axles. Such front axle loadings, while theoretically possible, are rarely achieved on typical general freight vehicles. Further, given the design of most tractors, loadings of 42,000 lb. on the drive axle (implying a spread of almost 8.2 ft. in Quebec) are generally not possible. A more typical maximum GCW on the Toronto-Montreal lane for tandem-tractor/ tandem-axle semi-trailer is around 94,800 lb. Nevertheless, it is appropriate to compare regulations in terms of "theoretically possible" rather than "typical" maximum GCWs, since the details of items such as axle spacing don't alter the basic issues being addressed.

It should also be noted that in all jurisdictions basic weight and dimension regulations can, and are, regularly circumvented by special permits. There are two basic categories of such permits, trip permits and operational permits. Trip permits are generally directed at facilitating overload or overdimension movements where the nature of the payload is such that it cannot be conveniently or economically broken into parts which would permit movements under current rules. Most jurisdictions issue literally thousands of trip permits each year. Operational permits are issued specifically to allow a special type of operation, usually with important conditions attached.

The authorization of over-length vehicle operation on divided highways (between Calgary and Edmonton, Saskatoon and Regina, Winnipeg and Brandon, and Montreal and Quebec City) is one example of an operational permit. Other examples include long-term overweight permits for the movement of special commmodities, such as potash hauled in Saskatchewan between Esterhazy and the U.S. border, and pulp wood hauled in Northern Saskatchewan. An important observation is that there appears to be a definite trend towards increasing the circumstances under which operational permits are issued.

4.2 Recent Trends and Pressures for Change

Rationale for Regulation

The three physical attributes of a highway that limit vehicle weights and dimensions are the roadway geometry (including vertical clearance), the load-carrying capability of the pavement, and the load-carrying capability of bridges. In addition, traffic engineering considerations, such as the effects of trucks on traffic flow and road accidents, also provide a basis for limiting vehicle size.

In some cases, the current regulations have no clear justification. The pre-1982 restrictions on gross combination weight limits on non-primary highways in the Prairie region can be cited as an example of arbitrary regulation of weight. Although no convincing justification could be made for the low weight levels, it was only after providing convincing arguments (such as standardization) for raising the weight levels that the limits were relaxed.

In general, the physical attributes of major roads do not impose absolute limits on vehicle weights and dimensions. Most major highways and bridge structures can, and do under special permit, accommodate vehicles which are substantially wider, higher, longer and heavier than the maximum allowable dimensions and weights. The apparent reasons for prohibiting such operations on a regular basis are largely economic rather than physical. For example, while a 10% increase in allowable axle weights might reduce the service life of a pavement, and therefore increase its average annual costs, the pavement would not be destroyed on the first pass.

It is important to recognize the distinction between potentially negative impacts such as the reduced service life of a bridge, and absolute physical limitations such as the impossibility of driving a 15-ft. high vehicle under a structure with a 14-ft. vertical clearance. Thus, proposals to further relax existing regulations may potentially have negative impacts, but are generally feasible physically. In most cases, substantial increases in weight and dimensions will not necessitate highway rebuilding but will have some adverse impact on the long-term cost of the highway. In the proper economic context, of course, the increased cost would have to be weighed against the benefits realized from the improved efficiency of trucking operations using larger and heavier vehicles.

Rationale for Change

The basic rationale for increasing allowable vehicle weights and dimensions is an economic one since larger vehicle combinations can handle freight more productively than smaller vehicles. Thus, payload capacity per unit of resource input typically increases with vehicle size. Although this is the fundamental rationale for the relaxation of weight and dimension regulations, proposals to achieve this are, in practice, often presented as a means of achieving uniformity in the regulations of different jurisdictions.

Differences in regulations pose practical problems for the trucker since he must conform to the lowest common denominator of all weight and dimension regulations applicable to the roads over which he operates. Uniformity, can, of course, be achieved at a level other than that of the most relaxed rules in existence, but in practice, the uniformity argument is always presented in terms of normalizing to the least restrictive case. In cases where contemplated changes involve more than one jurisdiction, it is often difficult for one jurisdiction to retain more restrictive weight and dimension rules than its neighbours. To do so could lead to relatively higher inter-jurisdictional trucking costs for shippers and consignees located in the restrictive jurisdiction than the costs of competitors located in more relaxed jurisdictions.

In recent years, another important reason for lobbying for more relaxed weight and dimension rules has been to enhance the competitive position of trucking vis-a-vis rail. This goal was, at least implicitly, part of the rationale for undertaking the Western Canada and Atlantic region highway strengthening development programs.

In short, weight and dimension rules are not "cast in stone." It is feasible to change them in ways that could alter the competitive balance between rail and truck on particular lanes and for particular commodity movements. This should be recognized as a distinct possibility in the face of more intense lobbying from the trucking industry, as well as from shippers and consignees, all of whom have a vested interest in lowering truck rates by pushing for regulatory change that will allow productivity improvements in the industry.

Current Activities

The weight and dimension regulations in Canada are under review by both provincial and federal governments. As noted above, nationwide uniformity is a fundamental issue in the current debate over weight and dimension limits. Lack of uniformity is often used to justify the relaxation of existing jurisdictional limits and is important in the lobbying efforts of the trucking industry and the shipping community. These arguments currently constitute the driving force behind efforts to relax regulations.

Although the basic relationships between axle loading, pavement design standards and maintenance requirements are recognized, little is known about their precise nature. Another phenomenon which is not well understood is the relationship between vehicle weight, type and size, and highway safety. In order to shed some light on these matters, the Roads and Transportation Association of Canada (RTAC) and the Canadian Conference of Motor Transport Administrators (CCMTA) have embarked on a major research project (RTAC 1982).

The purpose of the RTAC-CCMTA project is to assess the effects of variations in weight and dimensions on vehicle stability and control and on pavements. The project is scheduled to commence in April 1984 and is expected to run for three years at a total cost of about $3 million. The program will focus on both larger and heavier vehicles than are generally allowed in Canada. This in itself implies that the expected direction of changes in the regulatory environment is towards more liberal weight and dimension limits. It is also important to note that no major changes to existing regulations are likely to be made until after the completion of this study, in the hope that the results will further our understanding of the impacts of larger and heavier vehicles on both pavement design and road safety.

Another important development that is likely to influence changes in weight and dimension regulations in Canada is the report of the Uffen Commission in Ontario (Uffen 1983). The report recommends that the operation of over-length vehicles (triples, Rocky Mountain doubles and turnpike doubles) be prohibited in Ontario for the time being. The "for the time being" provision suggests that these units are still viewed as potentially applicable to the Ontario market, but that there is insufficient technical information currently available to make such decisions. It should also be recognized that Ontario often plays a lead role where such technical matters are concerned, and the rejection of these units in Ontario may provide the basis for prohibiting more extensive use of such units in other jurisdictions.

4.3 Expected Changes and Potential Impacts

Weights

As noted in the previous section, both the trucking industry and the shipping community continue to exert pressure on the regulatory authorities to relax weight limits. Under these pressures, certain changes appear likely over the next ten years. Given the highly subjective and political nature of the regulatory debate, however, it is not possible to predict the extent and the timing of these changes with any degree of certainty. All that can be done at this stage is to formulate scenarios which at least provide a framework for tracing changes in GCW limits over time (see Table 4.2). Although these scenarios are based on a careful assessment of the current regulatory environment, they are still highly judgemental and speculative.

In the immediate future, the standardization of weight limits throughout the Prairie provinces will be among the most likely changes. For single semi-trailer combinations, Manitoba and Saskatchewan limits will probably be relaxed to the current Alberta limit of 87,000 lb. Pressures will then

Table 4.2

Alternative Vehicle Weight Scenarios

(GCW in '000 lb)

	Current	Short term (0-5 years)	Medium term (5-10 years)	Long term (10 years +)
Singles				
Toronto-Halifax	106.9	106.9	**106.9-126.8**	**126.8+**
Toronto-Montreal	125.0	125.0	**125.0-126.8**	**126.8+**
Toronto-Winnipeg	82.0	**86.0-95.9**	**95.9-106.9**	**126.8+**
Toronto-Vancouver	82.0	**86.0-95.9**	**95.9-106.9**	**126.8+**
Doubles				
Toronto-Halifax	110.2	**110.2-118.0**	**118.0-124.6**	**140.0+**
Toronto-Montreal	126.8	126.8	**126.8-140.0**	**140.0+**
Toronto-Winnipeg	124.6	124.6	**124.6-140.0**	**140.0+**
Toronto-Vancouver	118.0	**118.0-124.6**	**124.6-140.0**	**140.0+**

mount for further relaxation of the limit for tri-axle trailers in the Prairies, which currently cannot carry more than tandem-axles in Ontario. A reasonable target for the Prairie limit for tri-axles over the next five years may be the current British Columbia limit of 95,900 lb.

In the medium term (i.e., 5 to 10 years), Western limits for single semi-trailer (tri-axle) combinations may continue to increase to weights beyond the 106,900 lb. now allowed in the Atlantic provinces. By this time, limits in Ontario and the Eastern provinces may have been increased to the current Quebec standard of 126,800 lb. It is then not unrealistic to expect the limits across the country (including the Western provinces) to reach this standard in the mid 1990s.

For double combinations, standardization of weight limits in the Prairie provinces is likely to occur in the immediate future. This will require the relaxation of Alberta and Saskatchewan limits to the current Manitoba standard. In the same time frame, another probable move will be to relax the Eastern weight limits for doubles, which currently are the lowest in the country. Over the next five years these may gradually be relaxed to the current Alberta and Saskatchewan limit of 118,000 lb., and soon after to the current Manitoba limit of 124,600 lb.

In about ten years (i.e., by 1993) the current Ontario limit of 140,000 lb. may become the nationwide standard. Changes in the Atlantic provinces may be delayed somewhat due to the restrictive limits that now prevail. Beyond the ten-year time frame, it would not be unrealistic to expect GCWs for double combinations to increase beyond 140,000 lb., especially in the Toronto-Montreal corridor.

The obvious impact of relaxed weight limits on trucking operations will be the reduction of unit costs. In Table 4.3, unit costs (cents per ton-mile) are estimated for the range of payloads corresponding to the weight scenarios presented above. As can be seen from Table 4.3, current unit cost for single semi-trailer combinations on the Western lanes (Toronto-Winnipeg

Table 4.3

Impact of Alternative Weight Scenarios on Unit Costs

	Current Unit Costs		Change in Unit Costs					
			Short term (0-5yrs)		Medium term (5-10yrs)		Long term (10yrs+)	
	¢/mi.	¢/ton-mi.	¢/ton-mi.	improvement (%)	¢/ton-mi.	improvement (%)	¢/ton-mi.	improvement (%)
Singles (tri-axles)								
Toronto-Halifax	144.13	4.03	4.03	-	3.22	20	3.22	20
Toronto-Montreal	138.64	3.15	3.15	-	3.09	2	3.09	2
Toronto-Winnipeg	137.35	6.00	4.74	21	4.05	33	3.22	46
Toronto-Vancouver	136.89	5.98	4.73	21	4.04	32	3.21	46
Doubles								
Toronto-Halifax	153.44	4.62	4.17	10	3.93	15	3.29	29
Toronto-Montreal	154.99	3.73	3.73	-	3.25	13	3.25	13
Toronto-Winnipeg	159.33	4.02	4.02	-	3.42	15	3.42	15
Toronto-Vancouver	158.12	4.35	4.02	8	3.42	21	3.42	21

and Toronto-Vancouver) is 6¢/ton-mi. If the limits were to be relaxed to the current Quebec standard, they would decline to 3.2¢/ton-mi. In the case of doubles, the highest unit costs are observed on the Toronto-Halifax lane. With an increase in the weight limit to 140,000 lb., unit costs may decline by as much as 29%, to 3.29¢/ton-mi.

In conclusion, the relaxation of weight limits to the current Quebec limit for singles and that of Ontario for doubles will achieve substantial reductions in the unit costs of both combinations. If the most restrictive cases are taken as the base (i.e., Nova Scotia for doubles, Manitoba and Saskatchewan for singles), the unit cost reductions will be in the order of 46% and 29% for singles and doubles respectively. These will translate to net productivity improvements for the trucking industry where capacity is constrained by weight limits ("weight-out"). In cases where dimensions pose the critical constraint on loads ("cube-out"), relaxation of weight limits will not result in any real benefits to carriers or, therefore, to shippers. In such cases, it is the relaxation of dimension regulations, that are significant.

Dimensions

As noted earlier, overall combination length for doubles is limited to 65.6 ft. in the Eastern provinces, 68.9 ft. in Ontario and Quebec, and 75.5 ft. in the Western provinces. All of these limits permit the operation of double-27s, but only with cab-over-engine tractors in the Central and the Eastern provinces. The 75.5 ft. limit in the West could also permit the use of somewhat longer trailers, but the further requirement of 55 ft. from "pin to rearmost trailer" allows only double-27s. Without this additional restriction, however, double-31s can be operated with an overall length limit of 75.5 ft.-78.7 ft., depending on tractor size and trailer spacing.

The relaxation of overall combination length to 75.5 ft-78.7 ft. may be among the first changes to be made to the regulations governing vehicle dimensions. Although it is not possible to predict the exact timing of such a change, it would not be unrealistic to expect the use of double-31s in about five years. This would have the impact of increasing cubic capacity by about 15% over double-27s, and lowering linehaul unit costs (i.e., ¢/100 ft.^3-mi.) by about 14% (see Table 4.4).

Another development that may take place within the next five years is the use of 48-ft. semi-trailers. These have recently been allowed in Ontario, and their use may spread to other parts of the country. As can be seen from Table 4.4, they provide 7% more cubic capacity with corresponding unit cost savings of about 6%. It should be noted, however, that as long as the restrictive Prairie province weight limits remain, longer singles will not offer significant advantages to carriers. In cases where cubic capacity is critical, carriers will naturally continue to use double combinations.

The use of larger combinations, such as Rocky Mountain doubles (a 45-ft. and a 27-ft. trailer), triples (three 27-ft. trailers) and turnpike doubles (two 45-ft. trailers) is highly speculative at this stage. Such over-length combinations may be permitted selectively on divided highways. However, major decisions concerning the use of such vehicles are unlikely to occur before the completion of the RTAC-CCMTA study. Use of these vehicles may occur in the medium term (5 to 10 years), but no sooner. There is, of course, always the possibility that over-sized vehicles will not be allowed on safety, or even political (such as pressure from the rail lobby), grounds.

If over-length vehicles are introduced, productivity gains in the trucking industry will be substantial. Taking double-27s as the base, cubic capacity increases by 34% with Rocky Mountain doubles, 50% with triple-27s, and 68% with double-45s (see Table 4.4). Corresponding unit cost savings are 24%, 29%, and 39%, respectively. At this stage, it is not possible to comment on the weight limits that may be imposed on over-length vehicles. In any event, on those traffic lanes where carriers typically "cube-out," these vehicles will have significant impacts on long-haul trucking.

Other changes in dimension regulations that can improve productivity in the trucking industry include vehicle width and height limits. As noted

Table 4.4

Impact of Large Vehicles on Capacity and Unit Costs

	Capacity ($ft.^3$)	Improvement* (%)	Unit Cost (¢/100ft.^{3}-mi.)	Improvement* (%)
Single-45	3350	-	4.13	-
Double-27	4000	-	3.82	-
Short to Medium Term:				
Single-48	3570	7	3.89	6
Double-31	4590	15	3.29	14
Medium to Long Term:				
Rocky Mountain Double	5350	34	2.91	24
Triple-27	6000	50	2.74	28
Double-45	6700	68	2.33	39

*Percentage improvement over double-27s for double combinations, and over 45-ft. semi-trailers for single combinations.

above, with some minor variations these limits are standard across the country at 102.4 in. for width and 13.6 ft. for height. By relaxing the width limit to 120.0 in. (as in the Northwest Territories) and the height limit to 14.8 ft. (as in Prince Edward Island), cubic capacity will increase and unit costs will decrease, as shown in Table 4.5. Although these changes are not expected in the near future (within 5 years), they should not be ruled out in the longer term.

Table 4.5

Impact of Increasing Vehicle Width and Height Limits (10.0 ft. x 14.8 ft.)

Vehicle Type	Capacity ($ft.^3$)	Improvement[2] (%)	Unit Cost (¢/100ft.^{3}-mi.)	Improvement[3] (%)
Single-45	4330	29	3.20	23
Double-27	5190	30	2.94	23
Single-48	4620	29	3.01	23
Double-31	5960	30	2.53	23
Rocky Mountain Double	6930	29	2.25	23
Triple-27	7790	30	2.11	23
Double-45	8660	29	1.80	23

*Percentage increase in cubic capacity from dimensions 8.5 ft. x 13.6 ft.

Chapter 5
ENGINE IMPROVEMENTS

In the last ten years, demands for improved fuel economy and the stricter emission standards have brought about many changes in the trucking industry. Engine manufacturers have concentrated on improving thermal efficiency, reducing mechanical friction, and limiting parasitic energy losses. These engine-related advancements have been credited with fuel economy improvements in the 15% to 20% range.

This chapter presents further engine improvements that are expected to improve the efficiency and, therefore, the fuel economy of the diesel engine over the next decade. In addition, viable alternatives to the diesel engine are examined. These technological improvements have been divided into three general categories. Engine efficiency improvements include turbocharging, charge air cooling, electronic engine control, reduction of parasitic energy losses, and other design improvements. Thermal efficiency improvements encompass turbocompounding, Rankine Cycle engines, application of ceramics and adiabatic diesel engines. The final category includes alternative engines such as the gas turbine engine and alternative fuels.

5.1 Engine Efficiency Improvements

Technological developments to improve the efficiency of the diesel engine are expected to continue over the next ten years with incremental changes gradually increasing fuel economy while reducing emission levels. These include advanced methods of turbocharging and charge air cooling, introduction of electronic engine control, reduction of parasitic losses, and a wide range of other design improvements.

Turbocharging

The performance of the modern large diesel engine is critically dependent upon the performance of the exhaust gas-driven turbocharger. The turbocharger increases engine efficiency by extracting work from the hot exhaust gas and using the energy to operate a compressor to pack more air into the cylinders. This allows higher cylinder pressures and increases the combustion efficiency of the engine. The turbocharger significantly influences engine power output, specific fuel consumption, thermal loading, and the ability of the engine to burn low-grade fuel successfully.

Although turbocharging has been used in diesel engines since the mid 1950s, the more efficient two-stage turbocharging was introduced to the heavy-duty diesel truck engine in 1981 by the Cummins Engine Co. (Robinson and Schnapp 1982). In order to achieve more power from the same engine displacement, engineers found it necessary to use twin turbochargers placed in series. The series turbocharger concept appears to be a cost effective alternative for high horsepower requirements (i.e., greater than 450 hp) and may be used more widely in the future, especially if vehicle weight limits are relaxed.

Efforts to improve the efficiency of turbochargers are now focusing on variable geometry turbocharging (Wallace et al. 1982). Variable geometry turbocharging enables the swallowing capacity of the turbine to be adjusted to give optimum turbocharger matching and improves torque backup, transient response, and fuel consumption over the full operating range of the engine. According to engine manufacturers, current turbocharger efficiency is in the 50%-55% range, and they hope to improve that to 60%-62% by 1990 with variable geometry turbochargers. This is likely to result in approximately a further 2% improvement in fuel consumption.

Pressure wave supercharging (PWS) is more common in Europe but may be applicable to North American heavy-duty diesel engines in the future as the trend to high torque, low rpm engines continues. Fuel efficiency is marginally better with turbocharging at high engine speeds, but PWS offers advantages at lower engine speeds. Pressure wave supercharging also provides higher boost at lower engine speeds and substantially lower transient smoke levels (Wallace and Aldis 1982). Pressure wave supercharging is currently an alternative to variable geometry turbocharging, but it is difficult to predict which system is likely to be adopted in heavy-duty diesel truck engines in the future.

Charge Air Cooling

Charge air cooling is the ideal supplement to pressure charging and all turbocharged engines incorporate some form of charge air cooling system. The cooling systems operate on the principle that at lower temperatures the intake air is denser and contains more oxygen. With denser induction air, the engine operates more efficiently, resulting in better performance, increased fuel economy and lower gaseous emissions.

The predominant method in use today for charge air cooling of truck diesel engines is the air-to-water heat exchanger, which uses engine jacket water to cool the charge air leaving the turbocharger to roughly the temperature of the engine coolant (from about 340°F to 185°F). Engine manufacturers are now trying to improve on this technology by rechannelling all but a small portion of the pump flow around the radiator. This achieves a greater temperature drop and provides a source of cold coolant to the charge air cooler. For example, Detroit Diesel Allison's low-flow system is capable of reducing charge air temperatures to about 135°F at full load conditions. Cummins has introduced a similar low-flow system to their basic 400 hp engine. Using existing radiator technology, low-flow systems can improve energy efficiency by about 2% over conventional systems.

An alternative charge air cooling system is the chassis-mounted air-to-air intercooler. This method obtains low charge air temperatures by installing the air-to-air heat exchanger in front of the cooling radiator. This design can achieve charge air temperatures of 110°F (Fleet Owner April, 1982). The air-to-air intercooler is generally more expensive because of the added cost of the piping and tubing needed to conduct air to and from the cooler. Moreover, different engine-radiator-tractor styles make it difficult for manufacturers to design the necessary air-to-air intercooler components such as ducts. Only Mack Trucks currently offers an air-to-air system. They have been able to overcome the associated design problems because they manufacture both the engine and the truck. In spite of these problems, however, it is generally recognized that air-to-air systems offer significant advantages, especially if lower inlet air temperatures are required. A new system proposed by Detroit Diesel, for example, is estimated to improve fuel economy by about 4%-5% while meeting the emission standards proposed for 1988 (Henriksen 1983).

Another system under development for obtaining reduced charge air temperatures involves the use of two coolant circuits. The system can be designed to use two water pumps which would permit the use of a second radiator and a totally separate flow circuit for the charge air cooler. Dual radiators can also be used in a single pump system, but the coolant flow must then be distributed between the two, with the front charge air radiator providing lower coolant temperature which is cycled directly back to the air-to-water heat exchanger. The dual circuit approach is more complex than the low-flow system but achieves lower intake air temperatures (Nutt and Poehlman 1982).

Electronic Engine Control

New electronic control systems are expected to play a major role in reducing emission levels and improving fuel efficiency. The timing and extent of future electronic engine control is largely dependent upon the direction of emission control legislation in Canada and the United States. It now appears that lower emission regulations in the U.S. will not take effect until 1988, and may be postponed even further if a decision is not announced soon. Sophisticated electronic engine control systems are now being tested but, owing to their expense, will not be incorporated into engine designs unless forced to by strict emission control standards.

A Japanese firm has developed an electronic engine control system with sensors that monitor engine speed and load, crank angle, altitude, ambient and exhaust temperature, oil and water temperature, and oil pressure. Microcomputers use the data to determine injection pressure and timing, and optimum turbocharger speed. The system provides better fuel economy, less smoke, reduced noise and emissions, quicker starting and greater durability (Fleet Owner June, 1981). Less sophisticated systems are currently in use and generally incorporate cruise control, tachographs and speed limiters. One such system, the Electronic Truck Engine Control System developed by TRW Inc., claims fuel savings of up to 13% (Fleet Owner April, 1982).

The major engine manufacturers are also working on electronic control systems with plans to market electronically controlled engines by 1986-87 to meet the proposed 1988 emission standards. The main objective of these systems is to electronically control fuel injection to optimize combustion efficiency, thereby improving fuel economy while lowering emission levels. A system which is currently being tested by Detroit Diesel Allison achieves 2%-3% better fuel economy, while meeting the lower emission levels proposed for 1988, by optimizing the timing of fuel injection. Additional gains can be achieved by using the electronic control system to limit vehicle speed by controlling engine droop (Henriksen 1983). In addition to improved fuel economy, the electronic system can be used to tailor torque and horsepower output to meet specific engine operating requirements. Furthermore the system improves the starting of the engine at colder temperatures by adjusting fuel injection rates and timing.

Other Engine Efficiency Improvements

The demand-actuated fan drive systems introduced in the mid 1970s have now achieved almost universal acceptance in the long-haul trucking industry. The fan clutch engages the cooling fan only when required thereby minimizing the power loss from the engine, as well as reducing engine noise.

Considerable progress has been made over the last few years to limit parasitic energy losses and engine manufacturers continue to improve water and oil pump designs in order to lower power requirements. Detroit Diesel Allison has developed a lube oil pump with a pressure regulator which senses pressure at the pump discharge to reduce oil pump horsepower losses. A thermostatically controlled oil cooler is also available. This maintains uniform oil temperatures, thereby reducing mechanical friction losses. The potential for energy efficiency improvements with such devices are estimated in the range of 4%-6% (Henriksen 1983).

Diesel engine manufacturers are continuing to incorporate design modifications into their new diesels to improve combustion efficiency and reduce mechanical friction. Over the next ten years low-friction cylinder components, improved intake port geometry, better camshaft and crankshaft design, and more efficient fuel injection systems with improved "in cylinder" swirl characteristics can be expected to improve fuel economy by about 3%-5%. The new Caterpillar fuel system, for example, achieves a 43% increase in fuel injection pressure and a 33% increase in the rate of injection (Connor and Stapf 1983). The use of smaller orifices with higher injection pressure improves fuel atomization. The new fuel system also decreases exhaust smoke levels and improves engine response time. Other design improvements introduced by Caterpillar include stronger cylinder heads (with compacted graphite iron) which can withstand higher cylinder pressures, and an improved piston, ring and liner package which minimizes frictional losses.

5.2 Thermal Efficiency Improvements

The current heavy-duty diesel engine achieves approximately 36% efficiency in the conversion of diesel fuel energy to mechanical energy. Of the remaining 64%, 36% is lost in the exhaust, while the remaining 28% is absorbed by the coolant. The technology exists to increase the efficiency of the diesel engine to 50%-60%. The challenge facing the engine manufacturers is to refine the technology to the point where it is economically viable. The two objectives actively being pursued by the engine manufacturers are, first, to convert the exhaust energy into useful mechanical energy and, second, to shift the waste coolant energy into the exhaust where it can be used to produce more mechanical energy.

Turbocompound Diesel Engine

One method to increase the thermodynamic efficiency of the diesel engine is to recover available exhaust heat beyond the turbocharger requirements by means of turbocompounding. This entails augmenting the diesel reciprocator with a low-pressure power turbine. Turbine power generated by exhaust gas expansion is transferred to the drivetrain by mechanically gearing the power turbine to the rear of the engine crankshaft at a fixed speed ratio.

The turbocompound diesel engine has been under development since the early 1970s. In 1978, under a program sponsored by the U.S. Department of Energy, Cummins tested two turbocompound NTC-400 diesel engines. The turbocompound engines were rated at 450 brake horsepower at 1900 rpm engine speed, compared to the regular NTC-400 which is rated at 400 brake horsepower at 2100 rpm (Brands et al. 1980). The lower operating speed rating was selected to take advantage of the low-speed torque characteristics of a turbocompound engine.

The two turbocompound engines were installed in heavy-duty vehicles to determine their fuel consumption and performance characteristics. During 50,000 mi. of commercial service on a cross-country route, the turbocompound engine yielded a 16% improvement in fuel consumption. However, not all of this improvement can be attributed to turbocompounding, since a number of other component modifications were made that also contributed to lower fuel consumption. Based on laboratory test results, the incremental fuel consumption improvement that could be attributed to turbocompounding alone was later estimated at 4%-5% (Brands et al. 1980). During the road tests, the turbocompound engine also achieved lower noise levels, improved driveability, improved gradeability, and marginally superior engine retardation.

In 1980, Cummins initiated an advanced turbocompound diesel engine program to further improve fuel economy. The advanced turbocompound engine maintained the same power rating (450 hp at 1900 rpm) as the earlier turbocompound engines but incorporated design improvements to increase the energy available from the exhaust gas at the turbine inlet, to improve the turbomachinery efficiencies, and to refine engine system optimization. The advanced turbocompound diesel engine was tested to produce an engine performance map, which was then used in Cummins' Vehicle Mission Simulation (VMS) program to estimate the resulting fuel consumption. The results showed a 6.5% improvement over the earlier turbocompound engines (Hoehne and Werner 1982).

The other major heavy-duty engine manufacturers are also actively pursuing the development of turbocompound diesel engines. Although turbocompounding has shown fuel economy improvements in the 10%-11% range, commercial development is still not attractive due to the additional cost of the power turbine and gear train. Efforts are now being focused on improving the gear system and reducing its cost. As discussed later in this chapter, improvements in high technology ceramics will facilitate the insulation of the diesel's combustion chamber. This will increase the available energy in the exhaust gas and make turbocompounding a more attractive proposition. As a result of these improvements, the turbocompound diesel engine may be in production by the late 1980s or early 1990s.

Rankine Cycle Engines

The Rankine Cycle engine uses a working fluid to produce power from an external heat source. A Rankine Cycle engine in itself is not particularly fuel efficient, but there have been encouraging results using this engine in conjunction with a heavy-duty diesel to make use of exhaust gas heat. In this process, known as "bottom cycling," exhaust gas passes through a heat exchanger to vaporize the working fluid. After the working fluid has been vaporized and superheated, it expands through a single-stage axial-flow turbine where the high thermal energy is transformed into high kinetic energy. The turbine's mechanical energy is then coupled to the engine's flywheel through a speed reduction gearbox and an overrunning clutch.

An organic Rankine Cycle system designed for use with a 288 hp heavy-duty diesel engine has undergone both laboratory endurance-performance testing and actual on-highway fuel economy comparison testing. The organic Rankine Cycle system uses an organic-based working fluid, trifluoroethanol, which can be mixed in several nonreacting mixtures with distilled water and has been found to be very effective in waste heat applications where the exhaust heat temperature is in the range of 550°-1000°F. The diesel-organic Rankine Cycle compound engine was installed in a Mack tractor-trailer unit for fuel economy comparisons. The actual on-highway vehicle tests obtained thus far indicate a 12.5% net improvement in fuel consumption for a long-haul tractor-trailer unit (DiBella et al. 1983).

The diesel-organic Rankine Cycle compound engine has demonstrated significant fuel economy improvements, but the system is complex, bulky, and heavy. The lighter, smaller and much simpler high-level turbocharged and turbocompound diesel appears better suited for a heavy-duty vehicular engine. The Rankine bottom cycle system may be used with adiabatic turbocompounded diesel engines, but this degree of sophistication is not expected for some time (Bryzik 1981).

Ceramic Technology

One of the most important material developments for improved thermal efficiency is the improvement of high technology ceramics to insulate the engine's combustion chamber. Ceramics possess the ability to retain their strength at high temperatures and are currently being tested as insulating materials for diesel combustion chambers. The four main types of ceramics being considered are silicon nitride, silicon carbide, partially stabilized zirconia, and silica glass-ceramic.

Silicon nitride, with significantly lower thermal conductivity and higher strength than silicon carbide, has received considerable attention as an insulating material (Ochiai 1981). Partially stabilized zirconia has very low thermal conductivity (approximately one-eighth that of silicon nitride), high thermal shock resistance and relatively less brittleness. However, the density is higher than the other materials and there remains some doubt about its performance at high temperatures. The glass-ceramic shows low flexural strength but has the advantage of very low coefficients of thermal expansion and thermal conductivity. The low expansion coefficient is attractive as it would allow pistons and liners with a very tight cold fit (Technology Ireland October, 1982).

The major technical difficulty with the use of ceramics as structural components is their relatively low tensile, or flexural, strength. The innate tendency of ceramic parts to fracture or shatter under stress is receiving considerable attention from researchers around the world. Looking at the microstructure, or the way the smallest particles of ceramic materials are bound together, researchers have found that ceramic parts are tougher if the particles are uniform in size. Several methods for forming "monosize" particles have been developed, including one that focuses laser light on gas mixtures to produce uniform-sized particles of pure silicon nitride or silicon carbide (Dizard 1983).

As efforts continue to produce stronger, more uniform ceramic components, the industry appears more confident about their applications. Other areas requiring further study include raw materials and powder processing, mass production techniques, high-speed precision machining, and reliable and practical methods for inspecting the finished components.

Adiabatic Diesel Engine

In thermodynamics an adiabatic process is defined as a no-heat-loss process. The adiabatic engine concept is to operate the engine near an adiabatic state by insulating the diesel combustion chamber with high temperature materials, primarily high technology ceramics.

Advantages of the adiabatic engine include virtual elimination of the conventional cooling system, an approximately 40% reduction in engine size and weight, and fuel efficiency improvements of more than 30%. Elimination of the engine cooling system, including cooling fans, radiators, hoses, shrouds and water pumps, will reduce engine weight and cost, and produce a quantum jump in reliability and maintainability as over 50% of engine failures in commercial heavy-duty vehicles are attributed to cooling system-related factors (Bryzik 1982). The adiabatic engine also reduces noise and provides scope for using alternative fuels.

Insulating the diesel combustion chamber increases the engine operating temperature and shifts the thermal energy normally lost to the coolant into the exhaust system where it can be recovered by turbocompounding. The increased power output, or alternately, the improved fuel economy is due primarily to the increased thermal energy recovery of the turbocompound system (Technology Ireland October, 1982).

Current turbocharged and intercooled diesel engines achieve approximately 36% efficiency in the conversion of diesel fuel energy to mechanical energy. Roughly 36% of the fuel energy is lost in the exhaust, while the remaining 28% is absorbed by the coolant. An adiabatic engine development program (with the U.S. Army Tank-Automotive Command and Cummins) has demonstrated 48% energy conversion efficiency with a 450 hp adiabatic diesel engine. Of the remaining 52% of the energy, 35% was lost to the exhaust system and 17% absorbed as cooling losses (Bryzik 1981).

The insulated high temperature components in the adiabatic engine include pistons, cylinder head valves, cylinder liners, exhaust valves and exhaust ports. A well-insulated combustion chamber can experience surface temperatures exceeding 2200°F and peak combustion pressures up to 2000 psi, occurring over high frequency stress cycles. Thus, the ability of a material to retain strength at high temperature and pressure over long periods of time is essential. As mentioned previously, ceramics offer the greatest potential under these conditions since they can withstand much higher temperatures than even the most suitable of the metallic materials, wrought alloys of iron, nickel and cobalt.

The transition from the current diesel engine to the adiabatic diesel is expected to be more evolutionary than revolutionary. Ceramics should start appearing in heavy-duty diesels in the late 1980s. Initially, ceramic-coated exhaust valves and exhaust ports will be used to increase the thermal energy in the exhaust gas to make turbocompounding more attractive. Engine manufacturers are thus hopeful for a production adiabatic diesel engine by the mid to late 1990s, but point out that it is dependent upon a ceramic technology breakthrough.

Further refinements to the adiabatic engine, including the use of components such as gas bearings, "ringless" pistons, low friction "dry" ceramic bearings and solid lubricants, are expected to lead to a "minimum friction" adiabatic engine. This can increase thermal efficiency to 54% and eliminate the engine oil system (Bryzik 1982). Further down the road a Rankine Cycle system may be added to extract more energy from the hot exhaust gases. Such a powerplant could be capable of achieving an energy conversion efficiency of about 63% (Technology Ireland 1982).

5.3 Alternative Engines and Fuels

Research efforts in the industry are also directed to new types of engines and alternative fuels. Although the diesel engine is expected to remain as the basic long-haul heavy-duty truck powerplant for the next ten to twenty years, it is still useful to review the results of research and development efforts into alternative engines and fuels.

Gas Turbine Engine

The gas turbine engine appears to offer the greatest potential as an alternative to the diesel engine as the heavy-duty truck powerplant of the future, although present automotive gas turbine engines suffer from lower fuel economy and a higher initial cost than comparable diesel engines. The basic technology, however, still provides alternative fuel capability and significantly reduced emission levels. Lower noise levels, lighter weight, and lower maintenance and operating costs also make the turbine an attractive power system for the future.

The Detroit Diesel Allison Division of General Motors and Industrial Turbines International (a consortium with Garrett Corporation, Mack Truck Inc., and Klockerner Humboldt Deutz) have conducted extensive research and development testing of a gas turbine engine for heavy-duty trucks. Detroit Diesel Allison was very active in the mid seventies but is no longer pursuing the development of a gas turbine engine for heavy-duty trucks. ITI is continuing development and testing of its GT601 recuperated open cycle gas turbine truck engine.

The GT601 truck engine program was initiated in 1972. Several engines have been built and tested, and at present over 7000 hours of operation and have been accumulated, 2000 of these with highway trucks (Olivier 1982). In these tests, the turbine-powered tractor-trailer has demonstrated significant performance advantages over a diesel-powered truck, especially in high gross weight applications. The GT601 program is aiming for gas turbine production in the near future for military applications. The gas turbine requires further fuel efficiency improvement and a reduction in costs before it can be put into commercial production for heavy-duty trucks.

The most critical area for improving the fuel consumption characteristics of the gas turbine revolves around increasing the turbine inlet temperature for improved thermodynamic efficiency. The optimum operating turbine inlet temperature is 2500°F), but current gas turbines with all-metal components are restricted to operation in the 1700°-1800°F range. The introduction of ceramic components in the hot section of the engine would substantially increase the allowable turbine inlet temperature, significantly improving fuel consumption. Replacing high-cost metal parts with low-cost ceramic or ceramic-coated components would also reduce the engine cost. Therefore, the use of ceramics appears to be crucial to the development of gas turbines.

Other Engine Developments

A number of other engine designs have received attention over the past few years as potential heavy-duty truck powerplants for the future. The opposed piston engine is one alternative which utilizes two horizontally opposed pistons operating on a two-stroke cycle with a common combustion chamber. This configuration has the potential for an efficient power-to-weight ratio with low noise, little vibration and a smooth torque output. The layout of the opposed piston engine could offer substantial advantages for the adiabatic engine. The combustion chamber formed between the two opposing pistons has a very small surface exposed to heat transfer, and it is an enclosure which can readily be made in high temperature material such as a ceramic. Other advantages stem from the absence of valves, the inherently compact shape, and the dynamics of the two-stroke engine cycle (Technology Ireland October, 1982). The engine is still in the preliminary test stages and is not expected to be in production in the foreseeable future.

The Stirling engine is an externally heated piston engine in which an entrapped gas is recirculated. One attractive feature of this engine is that any source of thermal energy can be used as input to the engine. The Stirling engine is a candidate for the long-term future, with no commercial application in heavy-duty trucks envisaged for at least ten years (Reader and Hooper 1983). The availability and cost of diesel fuel will, to a large extent, influence the timing of a production heavy-duty Stirling truck engine.

Wallace (1978) identified the stratified charge engine as a possible alternative engine for heavy-duty trucks. The stratified charge engine improves fuel economy by utilizing a two-stage combustion process to attain a very lean overall fuel mixture. Research and development efforts are now being directed toward the development of a stratified charge automobile engine with no application for heavy-duty trucks in the foreseeable future (Institute of Mechanical Engineers 1980).

Alternative Fuels

As noted earlier, diesel constitutes the dominant fuel in long-haul trucking. As petroleum prices rise, the trucking industry may come under increasing pressure to consider alternative sources. Although it is very unlikely that any alternative to diesel fuel would be considered in the next ten years, it may be worth noting some of the constraints that need to be overcome before any substitution could take place, as well as some of the opportunities that may arise in the longer term.

At present, there is no one source or process which will universally provide an alternative fuel to replace petroleum-based fuels. Instead, countries are exploiting their own resources to develop alternative fuels tailored to their domestic requirements. Canada has a variety of natural resources to draw upon, and methanol, ethanol, natural gas and propane are considered as near-term alternatives. In the longer term, synthetic hydrocarbons and liquid hydrogen offer potential in the transport sector. Within the time frame of this study, some of the near-term alternatives have potential applications in various segments of the transportation industry. The characteristics of long-haul trucking, however, are such that any substantial conversion from diesel fuel to alternatives is highly unlikely over the next ten years.

All the alternative fuels exhibit high octane numbers, low cetane numbers and require high ignition temperatures, which makes spark ignition (i.e., gasoline) engines more attractive for conversion than compression ignition (i.e., diesel) engines. At normal diesel compression ratios none of the alternatives will ignite without cetane-enhancing additives, or some form of ignition assistance. Thus, considerable modification to the diesel engine, in the form of a spark ignition or glow plug system, would be required to burn methanol, ethanol, natural gas or propane. One option is to use a dual fuel system with a pilot spray of diesel to ignite the main fumigated or pre-mixed charge. However, the need for two separate fuel storage and delivery systems makes this option unattractive.

Another disadvantage of the alternative fuels is that they all have a lower energy content per unit volume than diesel fuel. To facilitate comparison of the different fuels it is convenient to express equivalent energy content in terms of weight and volume, as shown in Table 5.1. Most linehaul tractors utilize two 125-gallon fuel tanks, which translates into roughly 20 GJ of energy per diesel fuel tank. Table 5.1 illustrates the fuel storage requirements for 20 GJ energy content for the various fuels. All the alternative fuels require more weight and volume to store on the vehicle than diesel fuel. For example, propane requires 1.70 times the weight and 2.15 times the volume compared to diesel fuel.

The capital cost of the conversion, the design problems associated with fuel storage and the added operational costs are presently greater than the savings in fuel costs for all of the alternative fuels. Until an alternative engine-fuel combination is developed which can compete with the diesel engine on the basis of both cost and convenience, there will be no significant market penetration of alternative fuels into the long-haul trucking sector. This does not appear likely within the next ten years.

5.4 Potential Applications and Impacts

The diesel engine is expected to remain as the basic long-haul, heavy-duty truck powerplant for at least the next ten to twenty years, but engine manufacturers will continue to concentrate on improving engine efficiency and durability. During that time planned improvements to the diesel engine will have a significant impact on the fuel economy and operating costs of linehaul tractor-trailers.

Since its introduction in the mid fifties the turbocharger has increased engine efficiency and improved engine performance. Further refinements over the next few years are expected to achieve an additional 1% improvement in fuel economy. Variable geometry turbochargers are now under development and should be in production by the late 1980s, giving approximately 2% better fuel economy than current systems.

Table 5.1

Fuel Storage Requirements for 20 GJ Energy Content

Fuel	Tank	Pressure	Weights in Kilograms				Volumes in Litres		
			Fuel Weight	Tank Weight	Total Weight	Wt/GJ	Fuel Volume	Total Volume	Vol/GJ
Diesel	Steel	1 atm	465.4	70.0	535.4	26.77	544.0	572.0	28.600
Gasoline	Steel	1 atm	445.8	78.5	524.3	26.22	612.3	644.0	32.200
Propane (LPG)	Steel	110 psig	430.6	480.4	911.0	45.55	861.5	1230.0	61.500
Methanol	Steel	1 atm	947.9	149.8	1097.6	54.88	1190.6	1260.0	63.000
Ethanol	Steel	1 atm	720.7	116.1	836.9	41.84	918.5	962.2	48.110
CNG	Steel	3000 psig	399.8	4156.2	4556.0	227.80	2366.4	3500.0	175.000
CNG	Steel	6000 psig	399.8	5430.2	5830.0	291.50	1550.8	2700.0	135.000
CNG	Kevlar	3000 psig	399.8	1102.2	1502.0	75.10	2366.4	3500.0	175.000
CNG	Kevlar	600 psig	399.8	1440.2	1840.0	92.00	1550.8	2700.0	135.000
LNG	Aluminum	1 atm	399.8	230.1	629.9	31.49	939.1	1332.1	66.603
LNG	Steel	1 atm	399.8	435.3	835.1	41.75	939.1	1332.1	66.603

Source: UTDC. 1982: p. 44.

A number of charge air cooling systems are currently being tested and will be incorporated into new engine designs over the next ten years. The low-flow aftercooling system will be introduced by some engine manufacturers in 1984 with fuel economy improvements of about 2% compared to existing air-to-water charge air cooling systems. Advanced charge air cooling systems, utilizing either air-to-air heat exchangers or dual cooling circuits, should be in production in the next five to ten years. The advanced systems will achieve lower intake air temperatures and improve fuel economy 4%-5%.

Electronic engine control systems are expected to be introduced in response to the stricter emission standards proposed for 1988. The main objective of the initial applications will be to control the fuel injection system for optimized combustion efficiency and lower gaseous emissions. The optimized injection timing will also improve fuel economy approximately 2%-3%.

Improvements to the water and lube oil pumps over the next few years will result in lower parasitic energy losses and attendant fuel economy improvements. Pressure regulators for lube oil pumps that minimize pumping losses and thermostatically controlled oil coolers that reduce mechanical friction losses are now being tested for production in 1985. These components can improve fuel economy 4%-6%.

Diesel engine manufacturers are also continuing to incorporate design modifications into their new engines for improved combustion efficiency and reduced mechanical friction. Over the next ten years, low friction cylinder components, improved intake and exhaust port geometry, better camshaft and crankshaft design, and more efficient fuel injection systems with improved "in cylinder" swirl characteristics are expected to improve fuel economy 3%-5%.

Thermal efficiency improvements, in the form of exhaust heat recovery, will substantially increase the overall efficiency of the diesel engine. The first step in this direction is expected in the late 1980s to early 1990s with the introduction of a turbocompound diesel engine. Recent testing of a turbocompound diesel engine has demonstrated fuel economy improvements of about 10%-11%. The effectiveness of the turbocompound unit will be enhanced by insulation of the diesel combustion chamber with high technology ceramics. This will enable the engine to operate at significantly higher temperatures, thereby improving combustion efficiency, increasing available thermal energy, and reducing cooling requirements.

The turbocompound diesel will initially utilize ceramic-coated exhaust valves and exhaust ports with further insulation eventually leading to an adiabatic engine by the mid to late 1990s. Techniques for making ceramic parts by injection-molding are advancing rapidly and will eventually eliminate the machining requirements which account for a substantial part of the cost of metal components. Thus, replacement of high-cost metal parts with low-cost ceramic components will reduce the cost of the engine as well as improve its efficiency. Further refinements to the adiabatic engine are expected to lead to a "minimum friction" adiabatic engine, and eventually a Rankine Cycle system may be added to extract more energy from the hot exhaust gases.

The major impact of the technological developments discussed above will be to improve the fuel efficiency of the heavy-duty diesel engine. As a result of engine improvements that are expected to occur in the short-term (0-5 years), fuel economy is estimated to improve by about 12% (see Table 5.2). Over the life of a typical tractor-trailer combination, this would represent savings of about $25,000 (in present value terms). These engine improvements, however, are not likely to add more than $10,000 to the purchase price of the tractor. The resulting net savings could then be expressed in terms of a 1.5%-2.0% reduction in unit costs (i.e., ¢/mi.) over the life of the engine.

As a result of further engine improvements that are expected to occur in the medium term (5-10 years), fuel economy improvements can reach

Table 5.2

Impact of Engine Improvements on Fuel Economy

Engine Improvement		Improvement in Fuel Economy (mpg) Over Base Year-1983
Short-Term (0-5 years):		
• improved turbocharger efficiency		1%
• low flow charge air cooling		2%
• electronic engine control		2%
• reduced parasitic energy losses		4%
• improved engine design		3%
	Total	**12%**
Medium-Term (5-10 years):		
• variable geometry turbocharging		2%
• air-to-air or dual circuit charge air cooling		4%
• electronic engine control		3%
• reduced parasitic energy losses		6%
• improved engine design		5%
• turbocompounding and ceramics		10%
	Total	**30%**

30%. Over the life of the engine, this would represent savings of about $52,000. The costs associated with the medium-term engine improvements are more difficult to estimate in advance, but they are not likely to exceed $20,000, or 38% of the fuel cost savings. The net medium-term impact could then be expressed in the range of 3.5%-4.5% reduction in unit costs.

Chapter 6

VEHICLE IMPROVEMENTS

This chapter summarizes the vehicle-related improvements which are being promoted to increase vehicle productivity and reduce operating costs. Fuel can represent up to 45% of the total operating costs of a linehaul tractor-trailer; therefore, the majority of the developments are aimed at reducing fuel consumption. An added benefit of some of these improvements is a reduction in vehicle tare weight. Another area of vehicle improvements focuses on vehicle weight reduction, allowing improved payload potential or, alternately, increased fuel economy.

Aerodynamic drag and rolling resistance account for roughly 90% of the total resistive force which the linehaul vehicle's engine must overcome at highway speeds. In recent years, considerable research has been directed toward the reduction of these resistive forces. Aerodynamic drag reduction has been achieved by improving tractor and trailer designs and by the use of add-on devices. Substantial reductions in rolling resistance have been made possible by new tire designs, construction techniques and improvements in tire materials.

6.1 Aerodynamic Drag

Aerodynamic drag reduction has received considerable attention over the last ten years. As the speed of the vehicle increases, the engine horsepower required to overcome the drag forces increases exponentially. Cab-over-engine tractors with van-type trailers encounter the greatest air resistance and therefore, have received the most attention from manufacturers.

The aerodynamic drag of a heavy commercial vehicle originates in four areas - pressure drag on the front and rear surfaces of the vehicle, skin friction over the body surfaces, and parasitic drag due to the rough, unstreamlined underbody components. For a typical tractor-trailer unit frontal pressure accounts for approximately 60% of the air resistance, rear pressure 14%, underbody drag 20%, and skin friction the remaining 6% (Cooper 1982).

Tractor, trailer and component manufacturers have largely concentrated on reducing drag on the forward-facing surfaces. Over the last few years tractors have been designed with rounded corners, angled windshields and fewer protrusions. Larger bumpers have been used by some tractor manufacturers to reduce underbody drag. Trailers have also been designed with rounded corners and smooth sides to minimize air resistance. The design of most linehaul tractors has been optimized to the point where very little aerodynamic drag reduction can be achieved without major changes to the tractor exterior. Although a number of experimental and prototype tractor designs have shown substantial reductions in aerodynamic drag, they are not expected to be in production for at least ten years.

The largest impact on aerodynamic drag results from the use of add-on devices. The cab-mounted wind deflector was the first device on the market to reduce aerodynamic drag. The deflector, typically a curved plate inclined at an angle to the cab roof, reduces the pressure on the trailer or van body front face through the sheltering effect of its wake, and eliminates the strong downflow behind the cab of a tractor-trailer unit. A well-designed and properly mounted wind deflector can reduce aerodynamic drag by as much as 15%. A major drawback of the earlier wind deflectors was that they increased drag when hauling flat-bed trailers or running bobtail. Some of the newer deflectors can be easily adjusted by the driver, thereby improving the overall effectiveness of the device.

Trailer forebody fairings were introduced shortly after the wind deflectors. The fairing is mounted on the top front section of the trailer or van body, providing a more streamlined shape. The fairing usually provides a smaller drag reduction than a deflector at low yaw angles, but its performance is constant, or may increase, at larger angles. The trailer fairing has the advantage that it does not have to be adjusted for best performance.

The cab-mounted roof fairing is closely allied with the wind deflector. It is more three-dimensional in shape, having the sides closed in. These devices generally achieve greater drag reduction as they are less yaw sensitive than deflectors. Wind tunnel tests indicate that up to a 24% reduction in aerodynamic drag can be achieved with the use of a wind fairing on a linehaul cab-over-engine tractor-trailer rig (Cooper 1982).

Tractor manufacturers are now designing and marketing add-on drag reduction packages specifically tailored to their tractor design. These packages usually include a roof fairing, cab side-extenders, and a specially designed bumper to act as an air dam. Cab side-extenders are plates behind the cab, the height of the cab, that extend the cab sides toward the trailer, partially closing the gap. The bumper air dams are designed to direct the air around the cab front to reduce underbody drag.

Freightliners' specially designed combination of roof fairing and side-extenders reportedly reduced aerodynamic drag by 30% in tests against a comparable cab-over-engine (COE) tractor-trailer unit not equipped with aerodynamic devices (Fleet Owner April, 1983). GMC has indicated that their new Aero package, designed for the COE Astro tractor, achieved a 32.8% reduction in aerodynamic drag in wind tunnel tests. Over-the-road tests of this package have shown 10% fuel economy improvements.

Other add-on devices designed to reduce aerodynamic drag are still at the experimental stage. Tractor and trailer skirts, for example, are currently being tested but are not expected to penetrate the market in the near future due to problems regarding maintenance and brake cooling, among other things. The specification of skirts in future truck designs may also depend on two safety-related factors, namely:

- shrouding the non-steering wheel assemblies may prevent potentially dangerous water spray generation; and

- in an accident, side skirts may prevent passenger vehicles from being trapped under the truck (Stollery and Garry 1983).

The preceding devices have all been subject to extensive testing by manufacturers in order to determine their overall contribution to drag reduction. Tests recently conducted in Europe by Leyland Vehicles have indicated that the application of a roof fairing, a single gap seal, tractor and trailer skirts, a base cavity, a bumper air dam and chassis filler panels could reduce aerodynamic drag by as much as 39%, with the roof fairing and gap seal providing most of this reduction (30%). Given this overall reduction in aerodynamic drag, a 20% improvement in fuel economy could be realized at highway speeds (Garrett 1981). Actual on-road applications, however, are expected to yield less significant improvements in aerodynamic drag and fuel economy. Given crosswinds, variations in load, and driving speed, the performance of some devices will be seriously affected, and subsequently, actual fuel savings will be lower than initially estimated. A relatively small increase in vehicle speed, for example, will cancel out any savings obtained from a reduction in aerodynamic drag.

Fruehauf's new prototype tractor-trailer unit, the FEV 2000, includes an aerodynamically efficient cab, roof fairing, automatic gap seal, front air dam, tractor and trailer skirts, and a boattail. Tests on this vehicle have revealed that the specifications of such a vehicle could reduce drag by as much as 57% and improve fuel consumption by 28% over that for a typical tractor with a dry-freight van (Fleet Owner July 1982). According to the manufacturer, however, it is doubtful that this experimental concept vehicle will reach the market stage in the near future.

The simulation model discussed in Appendix B was used in an effort to quantify the impact on fuel consumption of a number of aerodynamic drag reduction packages. The model results are shown in Table 6.1. As expected, the data indicate that better fuel economy can be achieved at lower speeds. However, as the aerodynamics of the vehicle are improved, the impact of speed reduction on fuel economy is reduced.

Table 6.1

HEVSIM Vehicle Performance Simulation Results
Aerodynamic Drag Reduction

Vehicle Modelled: DDA 8V-92TA 355 hp @ 1800 rpm
Power steering and fan clutch

Configuration	Aerodynamic Drag Coefficient	Aerodynamic Drag % Reduction	Fuel Consumption-mpg 55 mph	Fuel Consumption-mpg 60 mph	% Increase in Fuel Economy 55 mph	% Increase in Fuel Economy 60 mph
Base Case - GMC Astro	0.862	-	5.86	5.31	-	-
Cab-mounted wind deflector	0.733	15	6.26	5.69	6.8	7.2
Cab-mounted roof fairing	0.647	25	6.55	5.98	11.8	12.6
Fairing, gap seals, air dam	0.579	33	6.80	6.23	16.0	17.3
Fruehauf FEV 2000	0.431	50	7.42	6.86	26.6	29.2

6.2 Rolling Resistance

Rolling resistance between the tires and the pavement accounts for 30%-40% of the total force which the linehaul vehicle's engine must overcome at highway speeds. In recent years considerable research has been directed toward the development of new tire designs, construction techniques and tire materials to reduce rolling resistance, increase tire life and provide more responsive handling.

Radial ply truck tires have been on the market in Canada for more than ten years, offering improved fuel economy and longer tread life than bias ply tires. The radial ply design can achieve more than a 30% reduction in rolling resistance over the bias ply construction, which translates into fuel consumption savings of up to 15% at highway speeds. It is generally accepted throughout the industry that an 18-wheel linehaul tractor-trailer unit can improve fuel economy by 10% with radial tires. Tire manufacturers estimate that 70%-80% of the linehaul tractor-trailer units are now operating on radial tires. Recently, the industry has started to promote super single radials and new low-profile tubeless tires. Molded polyurethane tires are expected to be on the market in a few years.

The concept of replacing dual tires with a wide single is not new but has gained popularity recently in the long-haul market. New super single radial tires are claimed to have 10% or better tread mileage and 8%-9% better fuel economy than conventional dual radials (Fleet Owner Jan., 1983). In addition, the lighter weight of the wide-base single tire assembly permits higher payloads.

The Labatt's Ontario Breweries fleet has been evaluating wide-base radial tires for Michelin Tire Ltd. since November, 1980, and is running Bridgestone super singles as well. So far, the single tires have replaced dual radials on the tri-axle trailers only. According to the fleet supervisor, the wide-base tires have provided a 10% increase in Labatt's fleet fuel mileage (Diesel Equipment Superintendent Aug., 1983). Besides saving fuel, the single radials have incurred fewer flats and have recorded less downtime in general than dual radials. Another possible benefit from single tires is longer brake lining life because the wide tires expose more of the trailer drums for cooling. Another benefit is that the initial cost of the single tire is lower than for two radials used in dual positions. Labatts has now decided that all new trailers purchased will be equipped with wide-base single radials.

Initially some drivers were apprehensive about the new tires, and there were reports of instability with the narrower axles designed for duals. After going to wider axles, special wheels and new suspensions, the vehicles are said to handle better than with duals. Labatt's is now testing the new lower profile wide-base tires on three of their trailers. Michelin claims these tires will give 3%-5% better fuel economy than other single tires (Fleet Owner July, 1982). Labatt's is also planning to evaluate single tires on the drive axles of two tractors next winter.

The acceptance and market penetration of single tires is expected to progress gradually over the next ten years. However, the added cost of the special wheels and the possible instability of using the single tires on the narrower axles designed for duals will deter most fleets from switching to singles on their existing trailers.

Low-profile tubeless radial tires have recently been marketed for heavy-duty trucks after considerable success in the automobile sector. The reduced tire aspect ratio (section height/section width) decreases tire deflection, thereby improving vehicle handling and stability while increasing tread life and fuel economy.

Low-profile radials mounted on all 18 wheels of a tractor-trailer unit are claimed to provide 9% lower rolling resistance than conventional tubeless radials (Diesel Equipment Superintendent June, 1983). The lower rolling resistance results in fuel savings of up to 4%. In addition, manufacturers claim users can expect an overall increase in original casing life of up to 20%, with up to 25% increase in tread mileage over standard tubeless radials (Commercial Carrier Journal June, 1983). The low-profile tires are lighter and ride lower, resulting in up to 450 lb. of extra cargo capability on an 18-wheel rig and a reduction of 1 to 2 inches in vehicle height. The lower vehicle height, while possibly reducing aerodynamic drag, may cause problems in the matching of trailer and loading dock heights.

Molded polyurethane truck tires are currently being developed and tested in Europe by LIM Kunststaff Technologie, of Kittsee, Austria. The pneumatic, liquid-injection-molded (LIM) tires were first designed and tested as passenger car tires. Field tests of more than 2000 LIM tires indicate the potential for fuel savings of up to 12%, weight reductions of about 20%, a 50% cooler running temperature and up to 50% longer tread life in comparison with current radial and bias ply tires (Fleet Owner Sept., 1982). Another benefit is that the raw materials can be recycled. The company has recently started testing truck tires and expects to have a LIM truck tire available commercially in Canada within five years.

The impact of reduced rolling resistance on fuel consumption was examined using the simulation model. The four tires currently on the market were simulated and the radial tire is used as the base for comparison (see Table 6.2).

6.3 Vehicle Weight Reduction

The use of new lightweight materials for various truck components continues to offer commercial operators the opportunity to reduce vehicle tare weight. Over the last few years aluminum and, to some extent, fiberglass have been used to replace various steel components, producing significant weight reduction. The introduction of lightweight materials improves fuel economy for a given payload, or increases payload within GCW limits. The major obstacles still to be overcome, however, are the high cost of new materials and the development of automated fabrication methods.

Table 6.2

HEVSIM Vehicle Performance Simulation Results
Rolling Resistance

Vehicle Modelled: DDA 8V-92TA 355 hp @ 1800 rpm
Power steering and fan clutch

Configuration	Rolling Resistance Coefficient	Rolling Resistance % Reduction	Fuel Consumption-mpg 55 mph	Fuel Consumption-mpg 60 mph	% Increase in Fuel Economy 55 mph	% Increase in Fuel Economy 60 mph
Bias Ply	19.4	(54)	5.07	4.60	(13.5)	(13.4)
Radials	12.6	-	5.86	5.31	-	-
Low Profiles	11.4	10	6.02	5.43	5.0	2.3
Super Singles	10.2	19	6.47	5.81	10.4	9.4

Aluminum and fibre-reinforced plastic have become the primary cab and hood materials. Fiberglass is replacing steel in truck doors, offering lower weight and reduced cost. Add-on aerodynamic drag reduction devices, such as GMC's aero package, are made from lightweight plastic and fibre-reinforced plastic to minimize weight (Gregg 1983).

Aluminum and fibre-reinforced plastic are also the primary materials used in trailers today. Although the majority of vans are aluminum, fiberglass vans constitute a significant portion of the trailer population, despite their heavier weight. Some of the advantages offered by the fibre-reinforced plastic trailers include greater resilience to rust and corrosion, fewer maintenance requirements, increased interior space, and improved appearance. They were first introduced in 1978, but after a few years of rapid market penetration their popularity seems to be tapering off.

Future developments in lightweight materials will dictate the actual course of material substitution in both the tractor and trailer manufacturing industries. Aluminum is expected to continue to play a key role over the next few years. The development of a new casting alloy can now produce significantly stronger and more ductile aluminum castings with improved fatigue life. Compared to typical cast steel parts, this new alloy is 5% cheaper and 50% lighter (Koske 1982).

Composite materials of fibre-reinforced plastic are expected to be more widely used in the future, providing improved component performance and lower weight. A typical fibre-reinforced composite consists of fibres that carry tension or compression loads along the fibre axis and a matrix that binds the fibres together. The directional aspects of the composite strengths continue to present problems since loads must always be oriented along the fibre axis. Fiberglass, the oldest and most common fibre-reinforced plastic, is used in relatively low performance, non-structural parts. Higher strength fiberglass (eg., "S" fibre which is 50% stronger and 25% stiffer) is starting to be used in structural parts, but it is still very expensive.

Kevlar, the Dupont-registered trademark, is an improved fibre-reinforced structural plastic which is lighter, stronger, more impact-resistant, and extremely durable. It is, however, very weak in compression, difficult to work with, and very expensive. Carbon fibre displays high strength and stiffness characteristics and excellent fatigue properties. Although it is also easy to fabricate, carbon fibre is very expensive, brittle, and is not impact-resistant. In order to utilize desirable qualities of the pure fibres and compensate for their specific drawbacks, manufacturers now produce composites of two or more fibres. This is usually done by blending the fibres to form a hybrid fabric or by making plys from different materials.

Some of the prototype components in the industry have already incorporated some of these new materials. A Kevlar sandwich construction truck hood has been designed by Peterbilt, the weight of which is 75 lb. less than the conventional fiberglass version and is more impact resistant. Peterbilt is currently testing a steel and fiberglass-tapered leaf design front suspension spring which achieves a 40% weight reduction over standard steel design. Fiberglass and carbon fibre/fiberglass composite driveshafts have also been developed and tested by several manufacturers, achieving 50% weight reduction while producing the same torque capacity.

The industry has also been experimenting with sandwich construction techniques to produce lighter panel structures with increased stiffness. Typically, two skins or faces, made of gauge aluminum, steel or fiberglass, are bonded to cores of aluminum honeycomb, plastic, or plastic foam. Fruehauf recently introduced a fiberglass-reinforced foam core sandwich panel, which is now used in their refrigerated trailers. The sandwich composite concept provides a stronger and more thermally efficient trailer with up to 875 lb. reduction in weight (Edford 1982).

In general, experimentation with new lightweight materials is expected to continue. Over the next ten years, however, aluminum will remain the standard material in truck bodies. The cost of materials will continue to be the determining factor, since the reduction of tare weight is still a small factor in relation to the gross combination weights of long-haul tractor-trailer combinations.

6.4 Potential Applications and Impacts

Since frontal pressure accounts for approximately 60% of the air resistance, manufacturers have concentrated on reducing drag on the forward-facing surfaces. Over the last few years, tractors have been designed with rounded corners, smooth sides, angled windshields, fewer protrusions and larger bumpers. These basic design improvements have reached a stage where further reduction in aerodynamic drag cannot be achieved without major changes to the tractor exterior.

The largest impact on aerodynamic drag is expected to result from the use of add-on devices. Tractor manufacturers are now designing and marketing add-on drag reduction packages specifically tailored to their tractor design. Currently available wind deflectors, fairings and cab extenders range in price from $500 to $700, depending on the particular application. Given these low prices, the industry expects the use of add-on aerodynamic drag reduction packages to increase significantly over the next five years. Other devices such as tractor and trailer skirts, and gap seals are also expected to penetrate the market in the next five to ten years.

It is estimated that 70%-80% of linehaul tractor-trailer units in the industry now operate with radial tires. The market penetration of new tires is not expected to be rapid due to difficulties encountered in using more than one type of tire. Low-profile tires, which are currently priced between 6% and 12% higher than radials, are nevertheless expected to replace standard radials over the next ten years. Although it is unlikely that fleets will switch to super single tires on existing trailers, the acceptance and market penetration of these tires is also expected to increase gradually over the next five to ten years. The price of the super single tire is at present around double that of the conventional radial tire.

As documented in more detail in the previous sections, reduction in both drag and rolling resistance will have substantial impact on fuel economy. In the short term, as wind deflectors, roof fairings, and low-profile tires become standard, average fuel consumption can be expected to be reduced by about 12%, which will translate to operating cost savings of 3%. In the five-to-ten year period, as tractor and trailer skirts, gap seals, and super single tires become standard, average fuel consumption can be expected to decrease by about 25%, representing cost savings of about 6%.

The use of lightweight materials in various truck components will continue to remain at the experimental stage over the next five to ten years. Significant advances may be made in fibre-reinforced plastic technology, but further innovations in this area are not likely to cause the displacement of aluminum as the dominant material. In any event, since tare weight is only a small portion of the gross combination weight of a vehicle, the economics of material substitution are not likely to be governed by fuel consumption considerations.

Chapter 7

OPERATIONAL IMPROVEMENT

Over the past few years many for-hire carriers have started to take a serious look at new products, processes and systems aimed at improving fleet efficiency and reducing operating costs. In some cases, for example in the maintenance area, this has been partly in response to the requirements of more advanced engine and vehicle technology. In other cases, advances in information technology have provided carriers with opportunities for new system applications.

A detailed examination of operations and management related matters is well beyond the scope of this study. However, since some of the recent developments in this area are technology-related, this chapter highlights issues related to maintenance and information systems and, wherever possible, assesses their potential impact. It should be emphasized that this chapter constitutes only a preliminary investigation and that this area requires further study.

7.1 Maintenance and Repair

Maintenance and repair costs are a function of vehicle operating characteristics, driver behaviour, and fleet management policies. Vehicle operating characteristics include the type of equipment, gross combination weight, tractor and trailer utilization, road conditions and topography. Those fleet management policies that have a bearing on maintenance costs include scheduled maintenance intervals, preventative maintenance procedures, quality of parts, and materials.

The industry as a whole is trying to improve the durability and reduce the maintenance requirements of heavy-duty trucks. Engine manufacturers continue to make design improvements to increase the life of heavy-duty diesels. Current engines receive a major overhaul at 300,000 to 400,000 miles, but planned improvements are expected to increase this to about

500,000 miles by the end of the decade. Tractor and trailer manufacturers, on the other hand, are using more aluminum and fiberglass in their designs in order to increase vehicle life and reduce maintenance costs. While these basic design improvements are expected to continue, there are areas where the carriers themselves can take initiatives to improve maintenance practices. This is the focus of the remainder of this section.

Lubricants

The petroleum-based multi-viscosity lubricants that were introduced in the early 1970s have gained almost universal acceptance and will remain the industry standard for at least the next five to ten years. The increased use of oil-soluble friction-modifying additives will further reduce engine friction and increase fuel economy.

Synthetic lubricants were introduced in the late 1970s and have found increasing application and market share due to their flexibility and economy. The lubricants for transmissions and rear-axles have proven the most successful, largely due to their substantially greater durability. Petroleum-based transmission and rear axle lubricants require changing every 50,000 mi., whereas synthetic lubricants can last up to 250,000 mi. Although the price of synthetic lubricants is about twice that of petroleum-based products, they give 1.5%-2% better fuel economy, less wear on bearings and gears, better cold starting and substantial savings in maintenance costs (Fleet Owner April, 1983).

Although synthetic engine oil is good for 80,000 mi.-100,100 mi. it has not achieved the same success as the transmission and rear-axle lubricants, primarily because the oil filter still requires changing every 20,000 mi. Synthetic oil provides better hot and cold engine performance and less engine wear, with fuel saving estimated in the 3%-5% range (Fleet Owner August, 1982). Despite the advantages of synthetic engine oil, many fleet operators have found that the filtration problems, combined with the high cost of synthetic oil (four times that of petroleum-based engine oil) outweigh the advantages.

One major advantage of synthetic engine oil is that it does not break down at high operating temperatures. The higher engine pressures and temperatures made possible by advanced turbocharging, charge air cooling, and fuel injection systems have placed tougher demands on oils and lubricants. Future improvements, combined with the introduction of ceramic components, will increase cylinder pressures and combustion temperatures to the point where a switch to synthetic engine oil will become necessary. This may happen as early as the late 1980s.

Tires and Brakes

The majority of linehaul tractor-trailers are now operating on radial ply tires. The new low-profile radial tires improve vehicle handling and stability while improving fuel consumption and increasing tread and casing life. Tire manufacturers claim that the lower profile design achieves up to a 25% increase in tread mileage and an overall increase in the original casing life of up to 20% (Commercial Carrier Journal June, 1983). Molded polyurethane truck tires, which may be commercially available in five years, have reportedly demonstrated even longer tread and casing life in field tests in Europe.

Aside from improved rubber and synthetic compounds and better tire design and construction techniques, a number of other products are available to ensure that tires are well maintained and achieve optimum life-cycle use. A pressure equalization system is available that ensures equal tire pressure in dual tire assemblies. This prevents the overloading of one tire and the attendant increase in tread wear and possible tire failure. A low tire pressure sensor system is also available which notifies the driver, through a cab-mounted warning light, if a tire pressure has dropped below a prescribed limit.

Tire retreading innovations such as Flexcure now offer fleet owners another opportunity to reduce tire maintenance costs and increase the overall life of the tire. Essentially, Flexcure provides a better fit between the tire and the mold, improving tread adhesion and reducing separation. Other benefits of the improved retreading process include better tire balance and longer tread life.

Computerized tire maintenance systems are available, with industry sources quoting substantial cost savings due to extended tire life, reduced fuel consumption, and savings on vehicle downtime and road service (Fleet Owner February, 1983). Computerized tire "biographies" show the exact cost per mile for each carcass and can identify the abnormal tire wear that indicates a potential tire or vehicle problem. The system also keeps tight control on tire inventory, thereby reducing inventory excesses or shortages and pilferage.

Air disc brakes, initially introduced in the 1970s, offer considerable performance advantages over drum brakes. Disc brakes exhibit a tolerance for extreme overload, improved fade resistance, inherent balance, quick release time and better driver feel than drum brakes. The higher initial cost of disc brakes, although somewhat offset by maintenance costs, may impede their acceptance and widespread use over the next few years (Fleet Owner Feb., 1982). However, the industry is expected to eventually switch to disc brakes. As a preliminary step in this direction, some manufacturers have started to offer air disc brakes as a standard option.

Brake manufacturers are also concentrating on increasing brake life and reducing maintenance and repair costs. New materials developed to replace asbestos in brake linings provide significant reductions in maintenance costs. Dupont's aramid fibre, Kevlar, blended with mineral fibres produces composite friction materials that yield an approximately 35% increase in brake lining and drum life (Fleet Owner July, 1982). Other advantages associated with these new brake linings include increased brakeability and less fade. The development of automatic adjusting brake systems will also reduce brake maintenance costs.

Diagnostic Systems

Preventative maintenance techniques such as oil analysis and oil withdrawal have been available since the early 1980s, providing substantial savings in maintenance and fuel costs. Oil analysis programs sample and analyze oil. This catches problems as they develop and thereby helps to avoid breakdown costs and to extend engine life. One company has estimated in the first six months after adopting such a system, they saved over $25,000 in engine repairs for their 120-vehicle fleet. The cost of the system was estimated to be only $700/month (Fleet Owner February, 1982).

Oil withdrawal systems provide continuous oil change, removing oil from the running engine and replacing it with new oil from the reservoir. Advantages associated with this development include reduced downtime, improved fuel economy and increased engine life.

Computerized diagnostic technology for diesel engines is now available on the market. Cummins Ontario Ltd. claims that its new "Compuchek" system can cut diagnostic time by as much as 70% (Lockwood 1983). The Compuchek system is the first of its kind in Canada and the software is for Cummins engines only. The system is housed in a roll-around console with a hand held keyboard display and a printer. The microprocessor is hooked up to the engine, and can perform a complete engine health check in fifteen minutes. Sensors are attached to the engine to read data on engine speed, pressure and temperature. The computer then compares these readings with the engine specifications stored in the computer memory. The printout lists the tests conducted, acceptable, high, and low limits, and reports on test values.

In order to use Compuchek, an engine must be equipped with fittings to accept the sensor cables, and Cummins will provide blocks pre-drilled to accept the fittings. A complete engine health test will cost about $200 (checks on lube, cooling, fuel and air systems), with a test for low power or rough running done for about $125. The system is very easy to operate and takes the guesswork out of engine diagnostics. At the quoted prices, it is likely to be in widespread use in the near future.

7.2 Information Systems

Recent advances in information technology have created opportunities for more effective operational planning and fleet management in the for-hire trucking industry. The introduction of computers to the industry has already changed the operating practices of some companies resulting in substantial productivity improvements. Further developments in this area are expected to radically change many aspects of long-haul trucking. The following discussion attempts to highlight those issues that appear to be most relevant to the technology focus of this study.

Marketing and Planning

Most for-hire carriers operating on the four routes selected for the study conduct a large share of their business in less-than-truckload (LTL) traffic. In this market segment, commercial viability depends to a large extent on a carrier's ability to achieve a directional balance in their its loads. This in turn requires effective marketing in a highly competitive environment. It is in the carrier's best interest, therefore, to adopt sophisticated marketing strategies.

In long-haul LTL operations, market development activities could benefit a great deal from historical data which may reveal geographic, temporal and seasonal characteristics of past demand patterns. Coupled with current information on customers and their service requirements, analysis of trends could help identify opportunities and means of expanding markets in new areas. Some carriers have already started to experiment with computers in their marketing operations. With the state-of-the-art computer technology, there is considerable potential for major advances in this area. The carriers that are successful in capitalizing on this potential will be in a position to engage in much more effective planning and aggressive marketing.

The benefits of more sophisticated marketing strategies have already enhanced the competitive position of large LTL carriers in the United

States. As these carriers can balance their loads more effectively, they can offer lower rates and expanded services. Similar developments in the long-haul LTL markets in Canada can be expected over the next five years. As more and more carriers adopt advanced marketing strategies, they could also start to make collective use of large data banks and information retrieval systems.

Fleet Management

Computers have had some impact on fleet management practices in the last few years, but major changes are yet to occur with the advent of a new generation of computers which even small to medium-sized carriers can afford. Many carriers have already computerized their accounting and billing operations. In the near future, these companies will switch to more sophisticated systems which will gradually computerize all their information requirements, such as vehicle histories and driver records.

As electronics are introduced to engines, engine data can be directly fed into an information system and used for engine diagnostics, maintenance scheduling, and vehicle servicing and repair functions. The company can then evaluate the collected data on performance, breakdowns, and repairs to improve on current maintenance schedules and operating practices.

The vehicle-specific operating data which can easily be stored and retrieved will enable trucking firms to conduct functional cost audits. This practice will also enable the firm to take the necessary actions to trim costs, and will provide an improved basis for quoting rates to customers. An extension of the system can also enable the firm to computerize vehicle scheduling and routing to increase fleet utilization.

FOCUS, a cost-analysis program recently introduced by International Harvester, is an example of the computer tools currently available to the trucking industry. The program is now available to truckers in the U.S., and a Canadian version is planned once the U.S. system is fully operational (Sturgess 1983). This microcomputer system was originally developed as a sales tool, and it provides the truck operator with a means of predicting cash flows over the life of the vehicle and making replacement decisions.

The truck replacement analysis program compares the cost of running a fleet's current equipment with the total cost of replacing it. Factored into the calculations are the purchase price and balance owed, financing costs and salvage allowances, fuel consumptions, and the price of parts, labour and depreciation. Also included are tax credits, inflation, and interest rates. The results give year-by-year and truck-by-truck comparisons of the dollars spent or saved, and a summary showing net cash flow, savings, and the predicted optimum ownership period.

Driver and Vehicle Monitoring

The improvements in both engine and vehicle technology which were discussed in the previous two chapters will have only limited success in improving fuel economy if the necessary measures are not taken to enforce efficient driving habits. Some companies have already instituted training programs that promote fuel-saving driving habits. The programs generally emphasize progressive shifting, low engine speed, and reduced idling time, which in practice are successful in achieving fuel savings in the 5%-12% range (Energy Ontario 1983a; Energy Ontario 1983b). The major problem that the carriers continue to face, however, is to enforce efficient driving habits in order to sustain fuel savings beyond the experimental stage.

In this respect, the application of driver behaviour monitoring systems have started to receive some attention. There are a number of products that are currently available on the market and more sophisticated components are expected to be introduced with the refinement and increased use of electronics. One device which is gaining popularity is the tachograph, which records engine and/or vehicle speed, and can be checked after each trip for vehicle and engine speed, shifting patterns, engine idling time, etc. Many driver training programs now incorporate tachographs to monitor the driver's progress and point out areas where further instruction is required.

As referred to earlier, the introduction of electronic engine control systems facilitates the monitoring of engine performance, and any necessary data can be retrieved for diagnostic purposes. Once the use of electronics in trucks becomes widespread, the scope of monitoring can be expanded to all aspects of the vehicle and its operations. For example, the entire route profile can be monitored and transit times can be controlled by a central command unit to improve on-time performance. As shippers become more time-sensitive (as they have been in recent years), an on-route vehicle monitoring function may become an important element in trucking operations.

7.3 Potential Applications and Impacts

There are a number of developments underway that may achieve significant improvements in the maintenance area. Despite their higher costs, synthetic lubricants are now widely used due to their greater durability and their contribution to better fuel economy (about 1.5%-2%). Although they will continue to be more expensive than petroleum-based lubricants, higher engine temperatures will necessitate the use of synthetic engine oils in the near future.

Tire replacement costs are expected to decline because both the low-profile design and, particularly, the molded polyurethane tires (expected to be on the market in about five years), achieve greater tread mileage. Pressure equalization, low pressure warning, and computerized maintenance systems are also expected to contribute to lower tire costs.

Over the next few years the industry is expected to begin to switch to air disc brakes. These have a higher initial cost but have lower maintenance costs. New materials (such as the Kevlar-mineral fibre composite) developed to replace asbestos in brake linings offer significant maintenance advantages.

Substantial improvements can be achieved through preventative maintenance techniques such as oil analysis programs and oil withdrawal systems.

Computerized diagnostic technology, such as Cummins' "Compuchek" system, is now available and it can reduce repair costs substantially through routine "engine health checks."

Advances in information technology are expected to create opportunities for substantial operational improvements in the trucking industry. For example, there is a large, but yet unrealized potential for computer applications in market identification and development activities. Some large carriers may have already started to move in this direction, and over the next few years, a large segment of the industry can be expected to follow.

Computers are also expected to have a major impact on fleet management practices. Many carriers may start to computerize all of their information requirements. Engine data can be retrieved and used for diagnostic maintenance, as well as for the evaluation and modification of maintenance schedules and operating practices. Such systems can be extended to provide functional cost audits, using vehicle-specific operating data, as well as to facilitate more effective financial planning and budgeting in general.

Driver-monitoring systems can soon be in place to enforce the efficient driving habits that provide improved fuel economy. As shippers' demands become more time-sensitive, on-route vehicle monitoring systems can improve scheduling and on-time performance.

This chapter provides a brief introduction to the field of operational improvements and a preliminary assessment of their scope and their potential impacts. It is generally believed that widespread use of electronics in trucks and the application of computers to trucking operations will soon "revolutionize" the industry. The preliminary assessment of this poential, as summarized above, strongly confirms this view. This observation suggests that this area contains some of the most important changes that are likely to occur in trucking operations over the next decade and is therefore recommended for more detailed study.

Chapter 8

CONCLUSIONS

The environment in which the Canadian trucking industry operates is expected to undergo a number of changes over the next decade. The emergence of a more flexible economic system is foreseen in response to concerns for enforceability and, to a much lesser extent, "deregulatory pressures." Weight and dimension limits will very likely be standardized and gradually relaxed as the trucking industry continues to strive for greater productivity. Currently available technology is expected to see increased market penetration. In addition, new technological developments are scheduled for production within the next five to ten years.

Many of these changes will provide trucking fleets with the potential to reduce their operating costs. This chapter summarizes the regulatory and technological developments that are expected to occur over the next decade and the resulting impacts on unit costs. Since traffic characteristics and base operating costs vary across the country, the impacts are summarized for each of the four selected routes.

8.1 Regulatory Change

The existing **economic regulations** governing the for-hire trucking industry are under review in almost every province. The experience of deregulation in most spheres of transportation activity in the United States continues to fuel the regulatory debate in Canada. In practice, however, Canadian activities, particularly those of the Canadian Conference of Motor Transport Administrators, have been more concerned with the reform and clarification of interprovincial differences in the mechanisms of regulation. In general, the question of the enforceability of the present regulatory system is central to the review and reform process currently taking place.

The provinces that are nearing the mature stage of their review process appear to be moving towards the reform of some regulatory mechanisms and, possibly, the selective relaxation of others. But although some statutory controls may be removed, the for-hire trucking industry is not likely to be deregulated over the next ten years. More relaxed forms of entry tests (moving from "public interest" to "fitness" tests) may streamline existing practices, but will not necessarily have an immediate effect on the supply of for-hire trucking services. Given the excess capacity currently available in the industry, it is unlikely that the relaxation of entry controls per se would have a significant impact on either costs or rates.

As with for-hire trucking, probable regulatory change affecting **private trucking** will aim to clarify its definition rather than expand its scope. The potential use of private truck fleets for the purpose of for-hire carriage may have some cost and rate implications. A change in this direction is highly unlikely in the current regulatory environment, and even if entry requirements into for-hire trucking were removed, the impacts on costs or rates that currently prevail in the high density corridors are not likely to be significant.

Another issue of regulatory concern is the future of **owner-operators.** The employment of owner-operators by both for-hire and private carriers has increased in recent years. Although some definitional problems still exist, the regulatory systems have been flexible enough to accommodate this growth. If entry requirements are relaxed, owner-operators are likely to expand their role in the industry and operate as independent truckers, relying on freight brokers rather than for-hire carriers for their business.

Owner-operators can offer the industry a cost advantage of 12%-17% over company-owned vehicles with union drivers. Although rates may temporarily fall below this range (which represents owner-operators' fully allocated average costs including an appropriate remuneration for their labour) due to unusual market conditions, they are unlikely to be sustained at unreasonably low levels.

Over the next decade, there will be considerable pressure towards a nationwide standardization of **vehicle weight** limits. In general, changes to weight regulations are expected to occur on a regional basis first, with eventual standardization to the highest levels that are now in effect in Ontario and Quebec. The immediate changes are likely to be observed in the Prairie provinces where in addition to standardization (to the current Alberta limit for singles and Manitoba limit for doubles), there will be increasing pressure to relax tri-axle limits.

If gradual relaxation of GCW limits over the next ten years achieves uniformity around the current Quebec standard, payload unit costs on single semi-trailer combinations (measured in ton-miles of payload) may decline as much as 46% in the Prairie provinces and 20% in the Atlantic provinces. The standardization of GCWs for double combinations around the current Ontario limit may achieve unit cost savings of as much as 20% in British Columbia and 30% in the Atlantic provinces. It is, of course, possible that those provinces that currently have the least restrictive weight limits could relax them further in the next ten years.

Regulatory change concerned with **vehicle dimensions**, in particular with the use of over-length vehicles, is harder to predict. Standardization is likely to affect overall combination length, raising the limits in the Atlantic and Central provinces to what is now permitted in the Western provinces (75.5 ft.). However, regulation concerning the use of the larger combinations (Rocky Mountain doubles, turnpike doubles, and triples) will probably depend upon the findings of the RTAC-CCMTA study scheduled to be completed in 1987. If these combinations were permitted, however, volume unit costs (measured in cubic feet per mile) would decline substantially. Cost savings over double-27's would be about 24% with Rocky Mountain doubles, 28% with turnpike doubles, and 39% with triple-27's. The introduction of double-31's and widespread use of 48-ft. semi-trailers, however, should still be considered as likely developments in the short to medium term. The former would offer unit cost savings of 14% over double-27's, and the latter 6% over 45-ft. semi-trailers.

8.2 Technological Change

While considerable research is currently being conducted in the area of new engine design and alternative fuel utilization, engine manufacturers indicate that the diesel engine will continue to be the basic long-haul, heavy-duty truck powerplant for at least the next ten to twenty years. Therefore, manufacturers will continue to improve the efficiency and durability of both diesel engines and heavy-duty trucks.

A number of engine improvements are expected to have significant impact on fuel economy and linehaul operating costs over the next decade. Anticipated improvements in **engine efficiency** include variable geometry turbocharging and advanced cooling systems, such as air-to-air heat exchangers or dual cooling circuits. In response to stricter emission standards proposed for 1988, electronic engine control systems will be introduced, which in addition to lowering gaseous emissions, will improve combustion efficiency. Improvements to the water and lube oil pumps over the next few years will result in lower parasitic energy losses and attendant fuel economy improvements. Engine manufacturers are also introducing design improvements that will improve combustion efficiency and reduce mechanical friction. These engine efficiency improvements are expected to increase fuel efficiency by about 12%-30%.

Thermal efficiency improvements, in the form of exhaust heat recovery, will substantially increase the overall efficiency of the diesel engine. The first step in this direction is expected in the late 1980s to early 1990s with the introduction of a turbocompound diesel engine. The effectiveness of the turbocompound unit will be enhanced by insulation of the diesel combustion chamber with high technology ceramics. This will enable the engine to operate at significantly higher temperatures, thereby improving combustion efficiency, increasing available thermal energy, and reducing cooling requirements. The improvements are expected to reduce energy consumption by about 10%.

The turbocompound diesel will initially utilize ceramic-coated exhaust valves and exhaust ports with further insulation eventually leading to an **adiabatic engine** by the mid to late 1990s. Techniques for making ceramic parts by injection-molding are advancing rapidly and will eventually eliminate machining requirements, which account for a substantial part of the cost of metal components. Thus, replacement of high-cost metal parts with low-cost ceramic components will reduce the cost of the engine as well as improve its efficiency. Further refinements to the adiabatic engine are expected to lead to a "minimum friction" adiabatic engine, and eventually a Rankine Cycle system may be added to extract more energy from the hot exhaust gases. These developments, of course, fall beyond the time frame of this study.

Vehicle design improvements considered in this study include measures to reduce aerodynamic drag, rolling resistance and vehicle tare weight. The largest impact on **aerodynamic drag** is expected to result from the use of add-on devices. Over the next five years, the use of such devices as wind deflectors, roof fairings and cab extenders will very likely become standard, reducing fuel consumption by about 10%-13%. Other devices such as tractor and trailer skirts, and gap seals are expected to penetrate the market in the next five to ten years, with fuel savings reaching 16%-17%.

The introduction of low-profile and super single tires will reduce **rolling resistance**. Low-profile tires, with 2%-5% better fuel economy, are expected to replace standard radials over the next ten years. The gradual market penetration of super single tires, with 9%-10% better fuel economy, is also foreseen over the next five to ten years.

The introduction of lightweight materials may provide opportunities to reduce vehicle tare weight. However, material substitution is expected to remain at the experimental stage over the next ten years. In any event, the impact of such improvements on vehicle fuel consumption will be negligible since tare weight is only a small proportion of total vehicle weight.

A number of technology-related **operational improvements** are also expected over the next ten years. Improvements in maintenance and repair operations will result from the introduction of synthetic lubricants, tire pressure equalization and retreading methods, air disc brakes, and diagnostic systems. Advances in information technology will facilitate more effective marketing, operational planning, fleet management, and vehicle and driver monitoring. However, potential improvements in this area require further study before specific impacts can be assessed.

8.3 Cost Impacts

Typically, unit operating costs in the trucking industry are expressed in terms of cents per unit distance travelled. The impact of engine improvements in Chapter 5, and of reduced drag and rolling resistance in Chapter 6, can be expressed in terms of percent reduction in unit operating costs (per mile). Similarly, in the regulatory area, the lower costs of owner-operators can be expressed in percent savings in unit operating costs.

The comparison of these savings with those resulting from the relaxation of weight and dimension limits, however, may appear to be more problematic. In this case, unit operating costs of a vehicle may increase, but productivity is improved by the vehicle's capacity to carry larger or heavier payloads. Thus, cost savings can only be quantified in terms of unit payload costs, expressed as the cost of hauling a unit of payload (volume or weight) per unit distance travelled.

This problem can be overcome conceptually by translating all unit operating cost savings to unit payload cost savings. The percent savings due to a particular improvement will be the same in both cases as long as the payload capacity is not affected by that improvement. Since this holds true in all cases, where savings are expressed in terms of unit operating costs in this report (i.e., owner-operators, engine improvements and vehicle improvements), percent savings will be the same in terms of unit payload costs. Thus, those savings quoted in Chapters 3, 5 and 6 are additive with those from vehicle weight or dimension changes in Chapter 4, where savings could only be expressed in terms of unit payload costs.

The savings due to the relaxation of weight and dimension limits themselves, however, are not additive. In general, it is either volume or weight that limits the capacity of a truck. Where the former is more critical, truckers tend to use double combinations which provide greater volume before the weight limit is reached. In the latter case, single semi-trailers with, wherever possible, triple axles are the most common vehicle. Thus, payload increases on singles and the corresponding cost savings are likely to result from the relaxation of weight limits. On doubles, dimension limits are likely to be the governing factor, and it is the relaxation of these limits that are likely to result in cost savings.

Difficulties also arise in the comparison of unit cost savings due to variations between different routes. The use of owner-operators, for example, results in a 17% saving in the Western provinces compared to 12% in the Eastern provinces, since the current union wages are much higher in the West while owner-operator rates are not expected to vary across the country. Similarly, current weight limits in the Prairie provinces are much lower, and therefore there is far greater potential for reducing unit costs through achieving uniformity at the current Ontario or Quebec limits. The impacts of relaxing dimension limits and technological improvements, on the other hand, are independent of the route.

Tables 8.1 and 8.2 summarize percentage cost savings for single and double combinations on each of the routes selected for this study. The cost savings due to technological improvements are relatively small, reaching 6% in five years and 12% in ten years. The largest savings, particularly after 1988, are expected to result from the relaxation of weight and dimension limits. In the case of singles, savings are due to the expected standardization of weight limits towards the current Quebec limit. In the case of doubles, savings are due to the expected introduction of double 31's by 1988 and Rocky Mountain doubles by 1993. It should be noted, however, that the latter is highly speculative due to the uncertainty surrounding the future use of oversized vehicles.

Table 8.1

Summary of Unit Cost Savings
1983 to 1988
(in %)

	Toronto-Montreal		Toronto-Halifax		Toronto-Winnipeg		Toronto-Vancouver	
	Singles	Doubles	Singles	Doubles	Singles	Doubles	Singles	Doubles
Saving due to								
Owner-Operators	12	12	12	12	17	17	17	17
Weight Limits	-		-		21		21	
Dimension Limits		14		14		14		14
Engine Improvements	2	2	2	2	2	2	2	2
Vehicle Improvements	3	3	3	3	3	3	3	3
Maintenance Improvements	1	1	1	1	1	1	1	1
Total	18	32	18	32	44	37	44	37

Table 8.2

Summary of Unit Cost Savings
1988 to 1993
(in %)

	Toronto-Montreal		Toronto-Halifax		Toronto-Winnipeg		Toronto-Vancouver	
	Singles	Doubles	Singles	Doubles	Singles	Doubles	Singles	Doubles
Saving due to								
Owner-Operators	12	12	12	12	17	17	17	17
Weight Limits	2		20		33		32	
Dimension Limits		24		24		24		24
Engine Improvements	4	4	4	4	4	4	4	4
Vehicle Improvements	6	6	6	6	6	6	6	6
Maintenance Improvements	2	2	2	2	2	2	2	2
Total	26	48	44	48	62	53	61	53

In the short term (i.e., 1983-1988), total savings for singles range from 18% between Toronto and Montreal, to 44% on the Western routes (i.e., Toronto-Winnipeg and Toronto-Vancouver). From 1988 to 1993, the savings can be expected to increase to the 26%-62% range. For doubles, short term savings are likely to be in the 32%-37% range, potentially increasing to the 48%-50% range by the end of the ten-year period.

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Appendix A
TRUCK COSTING

The CN truck costing procedure was adopted to estimate common carriers' linehaul operating costs. Base year (1983) operating costs were calculated for the various vehicle configurations operating in the transport corridors under study, Montreal-Toronto, Toronto-Halifax, Toronto-Winnipeg, and Toronto-Vancouver, with emphasis on general freight traffic. The operating costs of interest are those incurred transporting the trailer from the origin terminal to the destination terminal, and therefore, terminal handling and administrative costs were not included in the estimated linehaul operating costs.

The common or for-hire carrier has three alternative means of transporting his trailer. He may use a company driver and tractor, hire a broker driver with a tractor, or ship his trailer with the railway (TOFC: trailer-on-flat-car). Linehaul operating cost estimates have been developed for both company drivers and broker drivers. An estimate of the common carrier's "avoidable cost" (those costs avoided by shipping his trailer by rail) were also developed. This cost (usually covering tractor ownership and maintenance, driver wages and fuel costs) is the theoretical railway rate ceiling, that is, the point at which the trucker is financially indifferent to using the rail system or going over-the-road.

The CN Competitive Truck Costing Manual (CN Rail 1983) outlines the methodology for the estimation of the highway carriers' variable costs and provides typical costs that are representative of common carriers engaged in linehaul operations. The CN approach utilizes a detailed cost accounting framework to develop operating costs for specific vehicle configurations operating over given routes. This approach offers the flexibility to address the impact of specific cost components on the overall operating cost picture, but requires the analyst to be quite knowledgeable about the operating characteristics of common carriers. The cost estimates provided in the manual are applicable to common or for-hire carriers, and indirectly to broker drivers, but not to private or contract carriers.

A.1 Data

1983 costs were taken primarily from the CN costing manual. Discussions with individuals associated with the for-hire trucking industry were used to supplement the CN data, modify base year costs, and estimate costs of future developments.

Table A.1 presents the basic data for the tractor and trailer combinations considered in this study. In general, 1983 purchase prices were taken from the CN costing manual. It was assumed that all owner operators purchase heavy-duty tractors to give themselves the maximum flexibility in load-carrying capability. Trailer manufacturers were consulted on the additional cost of the longer trailers (i.e., 31-ft. pups and 48-ft. vans) and they indicated that a cost of $125 per foot was the general rule of the thumb in the industry.

Table A.2 details the assumed annual utilization and equipment life for tractors and trailers. The annual cost factors for company-owned equipment were derived by CN. These factors are not strictly capital recovery factors since they reflect capital cost allowance and salvage value. The cost factors are applied to the total original cost of the equipment, less the cost of the tires. Tire replacement costs are calculated separately and 1983 tire purchase prices are listed in Table A.3.

The base year license and registration fees for the study corridors are listed in Table A.4. Annual tractor fees are a function of the gross combination weight carried and the distance operated in each province. Trailer license fees have been set at $3 per trailer per year. The annual insurance costs are shown in Table A.5.

Table A.1

1983 Equipment Prices

	Purchase Price ($)[1]	Tare Weight (lb.)[2]	Capacity (ft.^{3})
Tandem-Axle Diesel Tractors			
• Fleet Vehicles			
Regular-duty Sleeper	56,600	18,200	-
Heavy-duty Sleeper	63,100	20,700	-
• Driver Owned[3]			
Heavy-duty Sleeper	72,550	20,700	-
Dry Freight Vans			
• 45' Tandem-Axle	20,930	13,700	3350
• 45' Tri-axle[4]	28,674	16,200	3350
• 48' Tandem-Axle	21,300	14,150	3580
• 48' Tri-axle[4]	29,044	16,650	3580
• 2-27' Pup Unit[5]	40,031	24,500	4000
• 2-31' Pup Unit[5]	41,051	25,700	4620
• 45' & 27' - Rocky Mountain Double[5]	43,371	27,200	5350
• 2-45's - Turnpike Double[5]	46,711	29,900	6700
• 3-27's - Triple[5]	58,472	36,000	6000

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[1] Prices reflect discounts enjoyed by large volume purchasers and include radial tires as original equipment.

[2] Tare weights include 250 Imperial gallons of fuel.

[3] Purchase price is 15% higher than fleet's cost to reflect the lack of a discount and more options chosen by owner-operators.

[4] Purchase price includes the cost of the air lift axle.

[5] Purchase price includes the cost of the trailer converter dolly.

Source: Competitive Truck Costing Manual, CN Rail Costing, Exhibits 2 & 3.

Table A.2

Equipment Utilization

	Toronto-East			Toronto-West		
	Annual Utilization (mi.)	Service Life (yr.)	Annual Cost Factor	Annual Utilization (mi.)	Service Life (yr.)	Annual Cost Factor
Tractor						
• Company Owned	100,000	8	0.1733[1]	130,000	6	0.2177
• Owner-Operator	100,000	8	0.1850[2]	130,000	6	0.2186
Trailer	40,000	12	0.1319	52,000	10	0.1503

[1] Cost factors for company-owned equipment are taken from the CN costing manual.

[2] Cost factors for owner-operators reflect:

inflation rate of 6%
interest rate of debt of 12%
interest rate for savings of 8%
salvage value of 20% of the original cost

Table A.3

1983 Tire Costs

Tire	Purchase Price[1] ($)
Bias Ply	250
Radial Ply	328
Low-Profile Radial	345
Super Single Radial	692

[1] Purchase prices were compiled from the CN costing manual and Goodyear's truck tire price list (effective October, 1983). Prices reflect the discounts enjoyed by large volume purchasers.

Table A.4

1983 Licence and Registration Fees

Route	Total Annual Tractor Fees[1] ($)						
	Gross Combination Weight - lb.						
	85,000	110,000	120,000	125,000	130,000	140,000	150,000
Toronto-Halifax	2958	3810	4184	4324	4444	4671	4890
Montreal-Toronto	2262	2919	3185	3312	3424	3650	3865
Toronto-Winnipeg	2529	3141	3389	3408	3626	3872	4112
Toronto-Vancouver	5020	6361	6865	7169	7300	7751	8202

Trailer Licence Fee: $3/trailer/yr

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[1] Tractor licence fees are prorated based on the distance travelled in each province. Provincial board and/or insurance fees are cumulative.

Note: Existing provincial licence and board fees were extrapolated to derive estimates of the cost for heavier gross combination weight (GCW) tractor-trailer units.

Table A.5

1983 Public Liability, Property Damage and Cargo Insurance

	Annual Insurance Costs ($)		
	Linehaul Operation	City(P&D) Operation	Cargo Insurance
Tandem-Axle Tractor			
- Fleet Vehicles	4100	-	-
- Driver Owned	5400	-	-
45' & 48' Vans	1950	643	400
Double Pup Trailers	2160	689	600
Rocky Mountain Double (45' & 27')	2370	742	700
Turnpike Double (2-45's)	2370	742	800
Triple Trailers (3-27's)	2370	742	900

Source: Competitive Truck Costing Manual, CN Rail Costing

Table A.6 sets out the driver costs by route and tractor-trailer configuration. The major assumptions used to develop these costs are outlined at the bottom of the table. It was assumed that drivers operating single trailer units (i.e., 45-ft. or 48-ft. tandem or tri-axle vans) are all paid the same wage. It was also assumed that the wage rate for drivers operating double 31-ft. pup units will remain the same as that paid for the double 27-ft. pup configuration. The broker driver wages were estimated by CN costing from recent quotes. The extremely low broker driver wages on the Toronto-Halifax lane result from the stiff competition for backhauls among drivers carrying loads from the Maritimes.

Table A.7 illustrates the relationship between gross combination weight and fuel consumption developed from the HEVSIM computer simulation package (discussed in Appendix II). Due to a problem in the gear shifting algorithm, the model would only run vehicle simulations on flat terrain. To adjust the fuel consumption estimates to more accurately reflect realistic fleet operations, published figures on fuel consumption were consulted. This led to a decision to increase the HEVSIM estimated fuel consumption by 5%. The fuel consumption adjustments for route and vehicle configuration are shown beneath Table A.7.

Table A.8 lists the 1983 diesel fuel prices for large fleets. The maintenance and tire replacement costs are shown in Table A.9. The values were taken from the CN costing manual, with broker driver costs estimated to be 13% lower than fleet costs.

A.2 Analysis

In order to determine unit costs for the various future scenarios, a number of basic assumptions had to be made, both to ensure that the results of one set of analyses would be consistent with those of another, and to eliminate factors that might obscure the impacts of the scenario under examination. Consequently, all costs are expressed in 1983 dollars and no assumptions have been made as to potential changes in the real costs of

Table A.6

1983 Driver Cost

Company Driver Route	Driver Costs (¢/mi.) Configuration			
	45' Van	2-27' Pups	45' & 27' Double[1]	Triple 27s Double 45s[1]
Toronto-Halifax[2]	38.00	40.33	42.02	42.82
Montreal-Toronto[2]	36.69	37.56	40.70	41.50
Toronto-Winnipeg[3]	45.40	47.40	49.40	50.20
Toronto-Vancouver[3]	45.40	47.40	49.40	50.20

Broker Driver	Driver Cost (¢/mi.)
All routes	24.14

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[1] It was assumed that if over-length combinations were permitted on the selected routes, specially trained company drivers would be required to operate them and they would be paid a wage premium.

[2] Driver costs for the Toronto-Halifax and Montreal-Toronto routes are based on the CN costing manual's provincial wage rates. Driver wages are prorated based on the mileage travelled in each province. The driver costs reflect the basic mileage wage, supplementary wages, and an allowance for overhead (employee pension plans, U.I.C., Workmen's Compensation, etc.).

[3] Driver costs on the Western lanes are based on the Western Canadian Linehaul Agreement. One for-hire carrier estimated the present wage rate at 45.4¢/mi. It was assumed that drivers of double pup units receive an additional 2¢/mi.

Table A.7

Base Year Fuel Consumption

Gross Combination Weight (lb.)	Fuel Consumption[1] (mpg)
30,000	7.32
50,000	6.61
60,000	6.31
70,000	6.01
80,000	5.75
90,000	5.51
100,000	5.28
110,000	5.07
120,000	4.89
130,000	4.72
140,000	4.55
150,000	4.39
160,000	4.24
170,000	4.10
180,000	3.97

Adjustment to Base Fuel Consumption

Base: Montreal-Toronto route, single trailer unit

Fuel Consumption by Route[2]	Increase in mpg Over Base
• Toronto-Halifax	7.2%
• Toronto-Winnipeg	10.4%
• Toronto-Vancouver	11.5%
Fuel Consumption by Configuration[3]	
• Double Trailer Units	3.0%
• Triple Trailer Units	5.0%

[1] Fuel consumption is based on HEVSIM simulation data.

[2] Adjustments for the different routes are based on Caterpillar simulation results.

[3] Fuel consumption for double and triple trailer units is increased to reflect higher aerodynamic drag and increased rolling resistance.

Table A.8

1983 Diesel Fuel Prices

Province	Price (¢/gal.)
British Columbia	173.12
Alberta	133.53
Saskatchewan	135.80
Manitoba	169.53
Ontario	179.35
Quebec	197.25
New Brunswick	176.16
Nova Scotia	169.21
Prince Edward Island	194.12
Newfoundland	191.80

Note: Fuel prices are those as of May 1, 1983 and reflect the discounts enjoyed by large volume purchasers.

Source: Competitive Truck Costing Manual, CN Rail Costing, Exhibit 10.

Table A.9

1983 Maintenance and Tire Replacement Costs

	Fleet Maintenance Costs (¢/mi.)		
Tractor-Trailer Configuration	Tractor	Trailer	Total
Regular Service-Tandem Axle-Van	15.6	5.2	20.8
Regular Service-Tri-Axle Van	15.6	6.1	21.7
Heavy-Duty Service-Tri-Axle Van	16.8	6.7	23.5
Heavy-Duty Service Doubles	16.8	12.2	29.0
Heavy-Duty Service Triples	16.8	18.6	35.4

	Fleet Tire Replacement Costs (¢/mi.)[1]		
Tractor-Trailer Configuration	Tractor	Trailer	Total
Tandem-Axle Tractor With:			
• Tandem-Axle Van	2.2	1.6	3.8
• Tri-Axle Van	2.2	2.4	4.6
• Double Trailers	2.2	4.0	6.2
• Triple Trailers	2.2	5.6	7.8

[1] Steering axle tires 0.3 ¢/mi.
Other axle tires 0.2 ¢/mi.

Note: For broker drivers, tractor maintenance, repair, and tire replacement costs were assumed to be 13% lower than the fleet cost.

Source: Competitive Truck Costing Manual, CN Rail Costing, Exhibit 12.

items such as fuel and wages. These assumptions ensured that the influence of a given operating scenario on operating costs would be clear and, for example, that there would be no need to interpret the influence on unit costs that result from assumptions made about rising fuel prices. Clearly, if fuel prices rise faster than inflation, any technological developments that save fuel will have a greater impact on unit costs than indicated in the text of the report.

Unless stated otherwise, unit costs are presented for a fully loaded vehicle. That is, the payload is based on the maximum allowable GCW for the lane under consideration. Where cubic capacity is examined, the fully loaded volume is assumed to be 65% of the gross volume of the trailer (CN Rail Costing 1983).

Appendix B
ENERGY ANALYSIS

The major impact of the technological developments discussed in Chapters 5 and 6 is an improvement in fuel economy. However, predicting future fuel consumption for heavy-duty trucks is not a simple task, due to the wide range of design improvements, their varying degrees of effectiveness, and the variety of operating characteristics throughout the industry.

Published test results and manufacturers' promotional literature provide the primary sources of data on the reduction in fuel consumption resulting from specific improvements. This information usually originates in the United States, where speed limits, vehicle configurations, allowable gross combination weights, and operating characteristics differ from those in Canada. Consequently, these results are not directly transferable to Canadian operations. In addition, a total reliance on published fuel consumption data presents a second major problem because it is extremely difficult to establish a common base from which to compare the data on various new developments and to assess the benefits attributable to each one. Moreover, different measures aimed at improving fuel economy may not act independently of one another, and therefore, their effects cannot be treated separately or added cumulatively.

A further drawback when using published test results is that there is little opportunity to explore the sensitivity of the proposed improvements to operating characteristics. For example, most aerodynamic drag reduction devices are tested under favourable operating conditions at a single cruise speed, making it difficult to apply the resulting fuel consumption improvements to different operating speeds and conditions. Similarly, if published test data are used, it is difficult to assess the influence of driver behaviour on the effectiveness of improvements aimed at reducing fuel consumption.

Short of conducting field tests on all combinations of available technology in order to evaluate fuel economy improvements, computer simulation of vehicle performance and fuel consumption appears to be the most appropriate approach for assessing the impacts of technological factors. Vehicle performance simulation models have proven reasonably accurate in predicting the fuel consumption of heavy-duty tractor-trailer units. Vehicle performance simulation models facilitate the testing of a wide range of technological developments within a short time span and at a reasonable cost.

B.1 Vehicle Simulation Modelling

Over the past twenty-five years considerable work has been done in the area of computer simulation of vehicle performance. These models are designed to determine the performance and fuel economy of a specified vehicle as it travels along a given route under specified conditions. Simulating vehicle motion involves mathematically "driving" the vehicle along a route and accumulating information on elapsed time, distance travelled, fuel consumed and vehicle speed. Typically, for the same interval being evaluated, the requirements for torque and rpm at the wheels are determined from the desired acceleration and velocity.

Numerous models exist, many of which were developed for use in the automotive industry by vehicle, engine, and transmission manufacturers. In general, the programs use similar approaches to modelling, and they allow the user to provide a detailed specification of the vehicle to be simulated and the path which it is to travel. The vehicle is defined in terms of physical characteristics (such as its weight and dimensions), the engine and the drivetrain. The route description provides detailed information on grades, curves, signals and speed limits. In addition, the user may be able to specify how the driver behaves by defining acceleration rates and shift points.

Newtonian mechanics forms the basis for the evaluation of vehicle motion. For any time interval, simulation begins at a point of known position and speed. Acceleration, the rate of change of velocity (dv/dt), is integrated to find the vehicle speed at time t+dt1 using the approximation:

$$v_{t+dt} = v_t + a_t dt \qquad (B.1)$$

where v_t = velocity at time t
a_t = acceleration at time t
dt = time increment

Velocity is integrated using the trapezoidal rule to determine the distance travelled:

$$s_{t+dt} = s_t + \frac{(v_t + v_{t+dt})dt}{2} \qquad (B.2)$$

where s_t = vehicle location at time t.

The force of acceleration is defined as

$$M_e \cdot \frac{dv}{dt} \qquad (B.3)$$

where M_e = effective weight.

From Newton's second law, the required tractive effort is equal to the sum of the external (resisting) forces plus the inertial force:

$$F_T = F_r + F_a + F_g + F_c + M_e \cdot a \qquad (B.4)$$

where F_T = tractive effort (propulsive force) required
F_r = rolling resistance
F_a = aerodynamic drag
F_g = grade resistance
F_c = curve resistance.

The tractive effort may be positive, indicating a need for power, or negative, indicating a braking requirement. For any time increment, the required engine rpm and torque can be calculated once F_T is known.

Current research is being directed towards providing a better characterization of air resistance and rolling resistance. In practice, however, simulation programs model resistance with simple empirical equations that incorporate readily obtainable vehicle variables. For example, state-of-the-art rolling resistance modelling now uses a function of tire load and pressure. Current SAE practice reflects this (Procedures J1379 and J1380). However, all simulation models use a simpler expression for rolling resistance that assumes that resistance is proportional to vehicle weight, velocity, and road surface texture. Air drag is assumed to be proportional to dynamic pressure, which varies as the square of velocity. Wind and weather characteristics also influence aerodynamic resistance, as does the frontal area of the vehicle and the coefficient of drag, but not all of the existing models incorporate a wind component into the velocity term. Other models include variables to account for ambient pressure and temperature. Grade resistance is simply the product of the vehicle weight and the sine of the grade angle, while curve resistance, a very minor contributor to total resistance, is a complex function of vehicle and route characteristics. Due to its minimal impact, curve resistance is ignored in many simulation models.

The complexity of the characterization of powertrain components varies among existing models. Calculations proceed backwards from the rear wheels, through the rear axle, transmission and torque converter, to the engine. It should be noted that the order in which calculations are performed may differ from one model to another, and the procedure is presented here in very general terms. A more detailed discussion of powertrain modelling is provided by Blumberg (1976).

Power is transmitted from the driveshaft to the rear wheels through the rear axle. Given vehicle velocity, the rear axle ratio and the rear axle efficiency, the driveshaft rpm and torque can be calculated. From these values, the input to the gearbox can be determined using the gear ratios, the gearbox efficiency and the gear in which the vehicle is currently operating. For an automatic transmission, the output capacity factor of the torque converter can be calculated from the torque and rpm input to the gearbox. This factor facilitates the interpolation of the torque converter performance curves to determine the corresponding values of the speed and torque ratios so that engine speed and net engine torque can be calculated.

At this stage it is necessary to examine the gear being used. A user-provided shift schedule is inspected to determine whether or not the current operating assumption is correct. If a shift line has been crossed, a gear change is indicated and the calculation process iterates back to the gearbox where new values of torque and rpm are determined for the appropriate gear.

To model the engine, characteristic data on the relationship between gross power output, fuel consumption, and rpm are used. Typically, accessory horsepower is provided separately and is used to determine the net power output. There are two techniques that are generally used to provide the engine data. One is to input a table of data obtained from a fuel map of the engine (Buck 1981; Hwang 1969). These data provide detailed information on fuel consumption and power output over a range of rpm values. The procedure for interpolating between data points can be simplified greatly if the data are obtained from a plot of fuel consumption versus rpm. The second method uses these curves, which are generally provided in promotional literature on engines, rather than the more detailed fuel maps. The simplification results from the use of curve-fitting techniques to approximate these curves with polynomials (resulting in an input requirement of only a few data points rather than an entire fuel map). Second and third order polynomials have been used to provide accurate approximations (Smith 1970; Wollam 1971).

B.2 Performance Models in Industry

Most manufacturers of heavy-duty diesel engines have vehicle simulation programs developed specifically to model heavy-duty vehicles. These models are used both as research and development tools, and as aids to customers in their selection of appropriate vehicle configurations. The main heavy-duty diesel engine manufacturers supplying the U.S. and Canadian markets are Caterpillar Tractor Co., Cummins Engine Co., Detroit Diesel Allison, International Harvester, and Mack Trucks.

The Caterpillar and Cummins models are quite sophisticated, enabling the user to determine the vehicle performance and fuel economy of a specific vehicle configuration over a specific route such as Toronto-Montreal. The International Harvester model predicts specific vehicle performance and fuel consumption over typical highway, suburban, and city driving environments. The Detroit Diesel simulation model does not predict fuel consumption, and the capabilities of the Mack Trucks model have not been determined.

Although all of the industry simulation models derive from the same principles, little is known about their actual modelling processes. There are, however, obvious differences in the treatment of certain input parameters and component simulation procedures. For example, the approach to modelling rolling resistance adopted by both Caterpillar and Cummins is to input a rolling resistance equation for bias ply tires and modify the resulting values by a constant factor to account for other tire types (radials, low profiles, super singles). Not only does the rolling resistance for bias ply tires differ substantially between the two models, but the percentage decrease for other types of tires also varies. The estimation of accessory horsepower requirements and the treatment of aerodynamic drag reduction are other areas where model inputs differ.

Most manufacturers' simulation models have been carefully calibrated with data from over-the-road field tests, and have good correlation between predicted fuel consumption and actual performance. Caterpillar and Cummins have developed extensive data bases, which include many Canadian intercity routes, and this makes their models particularly appealing for use in this study.

B.3 HEVSIM

The examination of all appropriate technology options under a wide range of operating conditions requires a large number of simulation runs. At best, the research had only limited access to simulation models in the industry. This led to the decision to use an in-house truck performance model, since the sensitivity analysis of the technological developments under study would have been severely constrained if it were necessary to rely solely on the modelling capabilities of engine manufacturers.

HEVSIM, a numerical vehicle performance simulator, was developed for the U.S. Department of Transportation by the Research and Special Programs Administration of the Transportation Systems Center. This model is available for distribution to the public, unlike those within the trucking industry, so it was obtained for use in this study. The program is based on an automobile simulation model developed in the early 1970s. HEVSIM is a modified version designed specifically to evaluate heavy-duty truck and bus performance and fuel economy.

The simulation procedure used by HEVSIM is essentially that described in Section B.1. A detailed discussion of the modelling process is provided in Buck (1981) and is not repeated here. However, since rolling resistance and aerodynamic drag improvements constitute a significant portion of the simulation analysis, the HEVSIM specification of these resistance equations is presented here.

Rolling resistance is determined from the equation:

$$F_r = (C_1 + C_2 v_t)\ W/1000 \qquad \text{(B.5)}$$

where: C_1, C_2 = user-supplied input constants (lb./lb. weight)
W = vehicle weight (lb.)

Aerodynamic drag is defined as:

$$F_a = C_3 C_D A(v_t + v_w)^2 \cdot Y \tag{B.6}$$

where C_D = coefficient of drag
A = frontal area of the vehicle (ft.^{2})
v_w = wind velocity component parallel to the direction of the vehicle
C_3 = a constant defined within the program

and

$$Y = 1 + C_4 \tan^{-1}\left(\frac{v_n}{v_t + v_w}\right) \tag{B.7}$$

where v_n = wind velocity component normal to the direction of the vehicle
C_4 = a coefficient measuring the sensitivity of the drag coefficient to the yaw angle, which defaults to the value $C_4 = 0$

Data Requirements

Vehicle data required by HEVSIM include information on accessories, engine, torque converter, transmission, rear axle, tires, size, weight, aerodynamic drag coefficient, and shift logic. The user must also provide a route and compatible driving schedule.

The engine data supplied by the manufacturers is generally in the form of an engine performance or fuel map. The engine data input to HEVSIM relates engine speed (RPM) and engine output (torque or horsepower) to fuel consumption rate (lb./hr. or lb./bhp-hr.). The frictional horsepower or torque curve is also input so that engine motoring can be simulated. Engine accessories typically not incorporated into the engine fuel map include power steering, air conditioning, the alternator/generator and the cooling fan. This accessory data is specified at accessory rpm. The accessory speed, torque, and inertia are referenced to the engine through the speed ratio of the accessory gearing or pully arrangement.

HEVSIM has the capability to simulate both automatic and manual transmissions. A manual transmission is modelled as a locked-up torque converter, thus torque converter data for both a drive and a coast converter must always be provided. The converter input data relates input speed and torque to output speed and torque. The gear input data consists of input and output inertias, gear ratio, gear load efficiency and spin loss data. Discussions with transmission manufacturers have revealed that reliable spin loss data are not available, thus no spin loss data were used. This appears to be accepted practice both in industry simulation models and by other users of HEVSIM. Shift logic data are required to simulate gear shifts. The shift logic maps either engine or vehicle speed into appropriate throttle settings both for upshifts and downshifts.

The rear axle input contains data describing axle ratio, efficiency, and spin losses. Again, spin loss data were not input since discussions with axle manufacturers indicated that reliable data are not available. In addition, the industry representatives contacted indicated that spin losses are minimal, especially at high speeds.

The program considers all tires on a vehicle to be of the same type and thus allows only one set of rolling resistance coefficients to be input. The second order equation used to approximate rolling resistance (B.5) may be made linear by setting the speed-related coefficient equal to zero. The general industry approach to modelling rolling resistance, and that adopted for this study, is to establish a rolling resistance equation for bias ply truck tires and adjust the resulting values to account for different tires. In particular, the Cummins rolling resistance formulae (coefficients) have been used in HEVSIM.

Basic vehicle characteristics such as weight, drag coefficient, frontal area and the number of tires on the road are input. Improvements in aerodynamics are modelled by modifying the drag coefficient (C_D). For any aerodynamic package (or for a truck with no aerodynamic devices) the drag coefficient is derived from wind tunnel or on-the-road coast down tests. In HEVSIM, the yaw effects of crosswinds can be investigated through the specification of a drag sensitivity coefficient.

The route specification is used to identify distances and driving conditions. Each segment of the route is characterized by distance, grade, road coefficient and wind speed. The driving schedule is a specification of all accelerations, cruises, decelerations, and stops along the route, and the initial conditions are specified in terms of time, distance, speed, acceleration and gear setting. The driving schedule and route specification must be checked for compatibility when grades and winds are involved.

Table B.1 summarizes the main sources of information and provides a brief description of the types of data collected for the HEVSIM model. The torque converter and automatic transmission data from Allison Transmissions were promised, but have not been received. In general, the manufacturers have been cooperative in supplying the requested information. The exceptions have been the tire manufacturers and Caterpillar Tractor Co. The tire manufacturers will not release any rolling resistance coefficients, primarily because of the wide variations in their test results and the large number of factors which influence rolling resistance. Caterpillar does not release engine performance maps but have been cooperative in the provision of simulation runs.

B.4 Simulation Results

The evaluation of technological improvements made use of simulation results that came from two sources, HEVSIM and the Caterpillar truck performance model. The Caterpillar results were used to supplement the data provided by the HEVSIM runs, both for the validation of HEVSIM

Table B.1

HEVSIM Data Summary

Input Data	Source	Description
Accessory	Caterpiller, Cummins, Detroit Diesel	Accessory horsepower requirements for alternator/generator, power steering pump, air compressor, air conditioning and cooling fan.
Engine	Cummins Detroit Diesel	Formula/NTC-300, 350, 400 hp 8V-92A-355 and 445 hp
Transmission	Fuller Allison	RT-14609A: 9-speed manual RT-14615: 15-speed manual Torque converter and 5-speed automatic transmission.
Rear Axle	Eaton, Dana-Spicer	Rear axle ratios and efficiencies.
Tires	Caterpillar, Cummins, tire manufacturers, promotional literature, SAE publications	Rolling resistance formulae, and reductions in rolling resistance and fuel economy with new tire designs.
Aerodynamic Drag	General Motors, trade journals, SAE publications	Aerodynamic drag coefficients and the effects of add-on devices and manufacturers specially designed drag reduction packages.

results, and for the provision of data for scenarios that HEVSIM was unable to handle, or for which input data were not available. The latter purpose proved to be more important than had initially been anticipated. HEVSIM is unable to model grades properly for a manual transmission, although according to TSC, the transmission logic works properly on grades if an automatic transmission is used.

Given that grades cannot be modelled for manual transmissions, the intention was to use automatic transmissions to examine the effects of grade on the capability of a given engine and then extrapolate the results to the case of a manual transmission vehicle. However, the torque converter and gear data promised by Allison Transmissions was received too late to run a series of simulations to examine grade effects. Some of the runs provided by Caterpillar have been helpful for more general observations since they were run on specific routes (Toronto-Montreal, Calgary-Vancouver) which have differing route profiles.

The fact that HEVSIM cannot be run over grades severely restricts the analysis that can be done. One major problem concerns the assessment of the impact of weight on fuel economy based on HEVSIM results. There is no means of identifying the appropriateness of the engine specified without some measure of gradeability or the impact of grade on the performance of a given vehicle. One must make an educated guess as to the suitability of a particular engine for specified operating conditions. However, the basic trends that can be identified from a simulation using a reasonable choice of engine should hold for a more powerful engine should the engine used prove to be unsuitable.

A second problem is that driver behaviour cannot be evaluated in terms of shift points on grades, and since a truck operates at cruise speed for virtually the entire line-haul portion of the trip, there is little value in examining acceleration strategies. While runs from Caterpillar provided data on the difference in fuel consumption between the relatively flat

Toronto-Montreal corridor and the Western routes, shown in Table B.2, it has not been possible to obtain sufficient data to perform a more detailed sensitivity analysis.

Compatibility of Caterpillar and HEVSIM Results

Comparable Caterpillar and HEVSIM runs are presented in Table B.3. Output from the Caterpillar simulation model are compared with HEVSIM runs using similar Detroit Diesel and Cummins engines (8V-92TA and Formula 350 respectively). Since Caterpillar will not release engine maps, it was not possible to compare model results for the identical engine. All three engines have similar horsepower (350 for the Cummins and Caterpillar engines, 355 for that of Detroit Diesel) at 1800 rpm. Runs were made using essentially the same assumptions as identified in the table. However, for the aerodynamic devices, Caterpillar has modified their drag coefficients (from the accepted values) explaining that these coefficients were adjusted to provide fuel consumption figures that match those of their over-the-road measurements.

The table clearly indicates that even if one just uses data from HEVSIM, the results differ from one engine to another. This is due to differences in the fuel maps. When using simulation data, it is important to realize that the actual fuel economy provided by any simulation model should be interpreted with care. In general, the need to simplify reality results in an underprediction of fuel consumption since factors that increase it may be ignored in the simulation. However, the comparison of fuel economy for different scenarios should be reasonably accurate since the same assumptions hold for all data from a given model.

In general, the results from HEVSIM do not differ drastically from those of the Caterpillar model. If drag coefficients of similar magnitude are examined (as opposed to just looking at the particular aerodynamic option), the Caterpillar results still differ from the HEVSIM data. This suggests that the two models use different drag calculations. On the other

Table B.2

Route Analysis, Caterpillar Simulation

Vehicle Modelled:	CAT 350 hp @ 1800 rpm diesel engine Power steering with fan clutch GMC Astro (C_D = 0.72), no wind 60 mph 80,000 lb. GCW

Route	Fuel Consumption mpg	Percentage Increase in mpg
Toronto-Montreal	6.39	-
Toronto-Winnipeg	5.79	9.4
Winnipeg-Calgary	5.82	8.9
Calgary-Vancouver	5.51	13.8

Note: Caterpillar reduced rolling resistance on the Toronto-Montreal run by 17%.

Table B.3

Comparison of Caterpillar and HEVSIM Results

With the exception of the option specified, all runs assume:

- COE tandem axle tractor - GMC Astro
- 45' tandem axle semi-trailer van
- 80,000 lb. GCW
- Radial tires
- 9-speed manual transmission
- 3.55:1 drive axle ratio
- Power steering with fan clutch
- 60 mph

	CATERPILLAR			HEVSIM				
	Caterpillar Engine			Cummins Engine			Detroit Diesel Engine	
Option	C_D	mpg	% increase in mpg	C_D	mpg	% increase in mpg	mpg	% increase in mpg
GMC Astro	.72	6.39	-	.86	6.05	-	5.71	-
Wind Deflector	.61	6.79	6.3	.73	6.61	9.3	6.17	8.1
Roof Fairing	.54	7.09	10.9	.65	6.98	15.4	6.50	13.8
FEV 2000	.36	7.93	24.1	.43	8.28	36.9	7.56	32.4
Bias		5.54	(13.3)		5.14	(15.0)	4.93	(13.7)
Radials		6.39	-		6.05	-	5.71	-
Low Profiles		6.56	2.7		6.24	3.1	5.87	2.8
Super Singles		6.75	5.6		6.56	8.4	6.20	8.6
80,000 lb.		6.39	-		6.05	-	5.71	-
90,000 lb.		6.10	(4.5)		5.80	(4.1)	5.50	(3.7)
100,000 lb.		5.87	(8.1)		5.56	(8.1)	5.30	(7.2)
55 mph		6.88	7.7		6.76	11.7	6.30	10.3
60 mph		6.39	-		6.05	-	5.71	-

Note: ( ) indicates a percent increase in fuel consumption hand, the similarity in the results for weight variation indicates that the rolling resistance calculation is essentially the same in both cases.

These results indicate that it should be acceptable to make fairly general observations using a combination of the two models. Since it is unreasonable to expect to be able to make absolute statements about fuel consumption based on simulation data, the use of a combination of the two models to provide information on the impact of various factors appears to be a satisfactory approach.

Impact of Technology on Fuel Consumption

Rolling resistance and aerodynamic drag are the major determinants of fuel consumption, particularly when a truck is travelling on relatively level terrain. HEVSIM runs indicate that on level ground, aerodynamic drag and rolling resistance account for approximately ninety percent of the engine horsepower-hours used. The breakdown between the two components depends upon the vehicle speed and weight, and both range from forty to fifty percent of the total engine horsepower-hours. The other ten percent is attributable to the accessories, the differential and the gearbox. On grades, braking will also have a significant impact on fuel consumption.

In all discussion of simulation results, both in this Appendix and in other chapters of the report, the following scenario is used as the base for comparisons:

- COE tandem axle tractor
- 45-ft. tandem-axle semi-trailer van
- 9-speed manual transmission
- 3.55:1 drive axle ratio
- 80,000 lb. gross combination weight
- Radial tires
- No add-on aerodynamic devices ($C_D = 0.862$)
- 60 mph, no wind

Table B.3 identifies some fairly general (and expected) trends in fuel consumption. A reduction in the drag coefficient by means of an add-on device will reduce the fuel consumption, as will the use of tires designed to reduce rolling resistance. Increasing weight and/or speed effects an increase in fuel consumption, all else being equal. As expected, the model results indicate that better fuel economy can be achieved at lower speeds, with fuel savings in the order of 8%-12% when speed is reduced from 60 to 55 mph. This reduction remains relatively constant when changes are made to gross combination weight, tires and accessories. However, as the aerodynamics of the vehicle are improved, the impact of speed reduction on fuel economy is reduced. The data illustrate that the change from bias ply to radial ply tires has a greater impact on fuel economy than the upgrading of radials to either low profile or super single tires. For a truck already running on radial tires, greater (or at least equal) fuel savings can be achieved through the installation of simple aerodynamic aids (wind deflectors or roof fairings) than by changing the tires.

The simulation results indicate that it is not feasible to make a definitive statement about the reduction in fuel consumption that results from the use of the technology that has been examined in this report. The impact of any technological improvement under consideration is highly dependent on the truck configuration used in the evaluation. For example, the percent reduction in fuel consumption resulting from the use of any of the aerodynamic aids depends upon the weight of the the vehicle used in the analysis. Table B.4 summarizes the expected reduction in fuel economy for specified changes to the basic operating configuration used in the discussion of the simulation results. Note that the accessories are compared with a base case of air conditioning and a cooling fan, in order to identify the fuel savings that can be achieved through the use of a fan clutch.

Table B.4

Summary of Fuel Savings

	% Increase in mpg
Aerodynamics	
Wind deflector	6.5 - 9.0
Cab-mounted roof fairing	11.0 - 15.0
Fairing, gap seals, air dam	15.0 - 18.0
Freuhauf FEV 2000	24.0 - 37.0
Tires	
Bias	(13.0) - (15.0)
Low Profile	2.5 - 3.0
Super singles	5.5 - 8.5
Speed	
55 mph	7.5 - 11.5
Weight	
90,000 lb	(3.5) - (9.5)
100,000 lb	(7.0) - (8.0)
Accessories	
Air conditioning and fan clutch	5.0 - 6.0
Fan clutch, no air conditioning	7.0 - 8.0